BRITISH SEWAGE WORKS

M. N. BAKER

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AND

Notes on the Sewage Farms of Paris and on Two German Works

BY

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PREFACE.

This volume is devoted wholly to existing municipal sewage works, and is founded on notes of the works described made by the author during a tour of inspection ending in June, 1904. The book is, therefore, essentially practical rather than theoretical. Moreover, the statements made are semi-official, since descriptions of the several works have been submitted, in typewritten form, to the engineers, chemists and managers who extended courtesies to the author, and in 26 out of 27 cases have been revised by them. How the book came to be written is stated on page 9 of the Introduction.

The term "sewage works" has been adopted both because it is commonly used in Great Britain and because it is convenient and expressive. "Sewage treatment works" might be more completely descriptive, but is awkward. "Sewage disposal works" is too comprehensive a term and "Sewage purification works" would be, in many if not most cases, too pretentious. The term sewage works has been used but little if at all in America, but it seems that it might be adopted with advantage.

For the convenience of readers on both sides of the Atlantic both British and United States measures and money values, where differences exist, have been given. The desirability for so doing will be realized when it is remembered that the British or Imperial gallon is one-sixth larger than the United States gallon, and that a ton in Great Britain always means 2,240 pounds and a hundredweight 112 pounds; whereas in the United States, tons of both 2,240 pounds and 2,000 are used, making it necessary, or at least safer, here to specify whether a long or a short ton is intended.

In conclusion, both the author and publishers desire to thank the many friends in Great Britain and on the Continent of Europe who have aided in making possible the production of this book.

August 23, 1904. M. N. B.

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CHAPTER I.

INTRODUCTION.

There is a greater dissimilarity in the conditions affecting the treatment of sewage in Great Britain and the United States than is generally supposed. This dissimilarity includes differences in soil, climate, the personal habits of the people, municipal customs and professional standards. The soil, as a rule, is clayey and damp, requiring drainage to fit it for ordinary farming purposes. Sand and gravel suitable for filtering materials are scarce, thus necessitating recourse to cinders, clinkers and coke. The climate is more humid and less sunny than ours, although the total yearly rainfall in many sections is what we should call low. Personal habits and local usage in Great Britain favor economy in the use of water, thus tending to a very strong sewage, but the strength of the sewage in many municipalities is greatly reduced by the number of pails, dry earth closets and even old-fashioned privies and middens, which have not yet given way to water closets. On the other hand, combined sewerage systems are the rule in Great Britain, whereas in the United States separate systems are far more common, and few American municipalities with combined systems have yet built works for the treatment of sewage.

Professional standards in England, in so far as they relate to the sewage problem, are unlike those in the United States. Engineers, chemists and bacteriologists there more commonly take out patents on sewage purification or other sanitary works than do the same classes of men in the United States.

The density of population in many parts of Great Britain and the small size of the largest streams, when compared with our great rivers, and the existence of conservancy boards to prevent or lessen the pollution of streams in England have combined to force sewage purification upon that country much more rapidly than upon this. As a consequence, sewage works literally crowd upon each other in some parts of England. Even if the soil was favorable to the treatment of sewage it would be difficult, in more than one section, to find sufficient land at a reasonable price for sewage farming, and not easy to find enough for intermittent filtration. But the soil is rarely what one would choose, if a choice presented itself, for either broad irrigation or intermittent filtration. Moreover, the difficulties are increased

by the fact that most of the sewers are on the combined system, and the further fact that the Local Government Board insists, as a rule, on the treatment of a considerable portion of the storm flow.

Sewage is far more commonly pumped in Great Britain than in the United States. This increases the cost of disposal and leaves less money available for treating the sewage, but it gives greater freedom in the choice of methods of disposal than is possible where the location and arrangement of works is largely governed by the gravity head available for delivering the sewage where wanted for treatment.

The combination of the various factors cited has acted as a powerful stimulus to the search for new methods of sewage treatment in Great Britain, and the possible rewards for notable success doubtless account in part for the strong tendency toward proprietary processes.

Both fortunately and unfortunately for England, it has a Local Government Board which, through its veto power over permanent municipal loans not authorized by Parliament, controls to a very large extent the character of all sewage disposal works.* The existence of this board has been fortunate in that the board, amidst all the activity over new and diverse methods of sewage treatment, has, with a calmness and conservatism that have been almost maddening to those directly interested, passed judgment on each scheme and, when approving any new project, has insisted on what it considered to be adequate safeguards. The control of the Local Government Board over sewage works has been unfortunate because the board has been so largely a negative and so wholly a conservative force.

The nearest parallel we have to the British Local Government Board is the Massachusetts State Board of Health, but the latter body has been given both the legal power and the financial means to enable it to couple its power of veto and its virtual power of amendment of plans for sewage works with suggestions based on exhaustive experimental studies and practical observations. The Massachusetts State Board of Health, therefore, has been able to guide the municipalities under its jurisdiction, while the Local Government Board can do, or at least has done, comparatively little except to hold the municipalities of England and Wales to more or less arbitrary standards.

While the Massachusetts experiments have been conducted pri-

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*To secure Parliamentary sanction for a loan is likely to be a long and expensive process.

marily for the people of that State, their results have been studied and to a large extent followed by engineers and sanitarians throughout the United States. The leadership of Massachusetts would alone largely account for the fact that sewage disposal in America shows less diversity of method than is the case in Great Britain.

No one should be misled by the foregoing paragraphs into thinking that sewage treatment in the United States has become either settled or uniform. Far from it. There are evidences in many sections that the diversity so prevalent in British theory and practice has made itself felt here. American engineers who have had an opportunity to see for themselves what is being done in Great Britain have, for the most part, either continued to recommend the methods found acceptable in our own practice or else have advised experimental plants or one or two trial units before adopting a whole scheme based on British ideas.

Unfortunately, every American engineer cannot go abroad for the purpose of studying sewage disposal works, and naturally the few who can and do go do not feel called upon to make public the whole result of their investigations. British engineers and chemists have written numerous books and papers on sewage disposal, but of late these have dealt more with the theoretical and experimental work than with plants in every-day use. It therefore became true that for many years, in neither Great Britain nor America, was there any comprehensive description of the representative British sewage disposal works of the day.

In the early history of American works for the treatment of sewage, Engineering News commissioned the writer to prepare a series of articles on "Sewage Purification in America." Those articles were collected and reprinted in 1893, and comprised descriptions of nearly if not quite all the municipal plants for the treatment of sewage then existing in the United States. A large percentage of the descriptions were based on visits by the author to the works described.*

Some ten years having elapsed, during which many new, or at least modifications of old, methods of sewage treatment had come to the front, particularly in Great Britain, the writer seized an opportunity, generously afforded by Engineering News, to visit

*Subsequently the author of the present book joined with Mr. George W. Rafter, M. Am. Soc. C. E., in the production of "Sewage Disposal in the United States," which was the first comprehensive American treatise on the theory and practice of sewage disposal.

a large number of representative British sewage works and to meet many of the leading British experts in sewage disposal. The result is the present book, which, it may be added, is primarily descriptive of the works visited.

Twenty-four British sewage works were visited by the writer between March 20 and June 20, 1904. It is believed that these works are fairly representative of British sewage disposal practice of to-day. They include examples of both old and new methods of treatment and also of both large and small works.

Aside from five sewage farms and three chemical precipitation plants, the works combine two or more methods of treatment and are not easily classified. The readiest and perhaps the most reasonable basis of classification for the 16 combined works appears to be the final method of treatment employed. Using this classification, we have eleven works with contact beds,* and five with percolating filters, besides the five sewage farms and three chemical precipitation plants already mentioned.

The preliminary treatment at the 16 combined works consists principally of septic tanks, for part or all of the sewage. Some of the works make use of sedimentation for all and others for a portion of the sewage treated, and still others employ chemical precipitation in like manner. The majority of the septic tanks are open.

The paragraphs immediately preceding summarize briefly the main features of the works visited. A broader view of the whole subject suggests the following conclusions and comments on sewage treatment in Great Britain:

Chemical precipitation is rapidly giving way to plain sedimentation and to septic tanks, more generally the latter, but many precipitation works are still in operation, and even now Glasgow is steadily proceeding with the construction of a series of such works. The conditions at Glasgow, however, are exceptional. It should be remembered that few figures have yet been published which enable one to make an accurate comparison of the relative costs of chemical precipitation and of effecting the same results by the newer methods of treatment. Most of the comparisons thus far made include operating expenses only. More figures relating to capital charges are needed.

*For the convenience of any readers not familiar with the processes of sewage treatment now in use, definitions or brief descriptions of the same have been prepared and may be found in an appendix to this book.

Sewage farming has by no means come to an end, although in many instances it is being abandoned as rapidly as local circumstances will permit. Not a little of the apparent failure of sewage farming has been due to the faulty methods employed as preliminary to the application of sewage to the land. Where the land available for sewage farming is defective in quality or deficient in quantity, it has been necessary to resort to a preliminary process of sedimentation, chemical precipitation, or some method of filtration, and this necessity has furnished the opportunity for exploiting the conceits of visionaries and of the proprietors of a multitude of patented processes of sewage treatment. Most of these processes have proved either futile or ruinously expensive, but too often the condemnation for their failure has been heaped on sewage farming instead of on the preliminary treatment.

It should be explained for the benefit of those unfamiliar with the history of sewage treatment in England and Wales that for years past the Local Government Board, which controls most municipal improvements involving loans, has insisted on the final application of sewage to land, regardless of the previous method employed to treat the sewage.* This has virtually made sewage farming a necessity, wherever any departure from discharging crude sewage into a stream or the sea has been adopted. Acting under compulsion, it is not strange that municipalities and their engineers and farm managers should often lay out and operate sewage farms in a makeshift fashion. While sewage farming in Great Britain has suffered unjustly at the hands of both its friends and its enemies, there is little in the conditions prevailing in that country to indicate that it would be a success in the United States, except in those sections where every drop of available water is needed for ordinary irrigation.

Intermittent filtration plays so subsidiary a part in Great Britain, and is so different there from what it is here, that we have little regarding it to learn from British practice. Nor does there seem to be much reason, based on British experience, why we should hasten to change from intermittent filtration to more rapid bacterial processes. It would seem to be worth while, in the case of new works, to make estimates of the cost of intermittent filtration as compared with contact and percolating filters.

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*Recently this requirement has been modified in certain instances.

Septic tanks have not eliminated the sludge problem, as was claimed for them at the outset, nor has it yet been fully determined what percentage of sludge they will eliminate nor what can best be done, in the case of very large works, with such sludge as is produced. In the case of municipal plants, at least, it appears that most of the tanks thus far built are open, and many British engineers and chemists believe that open tanks are as efficient, and, as a rule, in other ways as satisfactory as closed tanks. In cold climates the closed tank may be advantageous on account of conserving heat and, in proximity to dwellings and highways, covers may also be desirable to prevent possible annoyance to people in the vicinity.

Contact beds have certainly made more headway than percolating filters as final means of treatment in Great Britain, but at present the percolating filters seem to be forging toward the front. Here again we lack figures for capital charges and operating expenses under the two systems. It seems to be pretty well agreed that contact beds alone are insufficient, even with double contact, and that double or triple contact is required where a high degree of chemical purification is required. Automatic apparatus for filling and emptying the beds is common but by no means universal either in practice or in the opinion of engineers and chemists. The best material for contact beds does not seem to have been settled, but the most common is cinders or clinkers, the clinker from refuse destructors having the preference. Most of the British contact beds have water-tight bottoms and sides, the necessity for which is not always apparent.

Percolating filters are a later development than contact beds, and, as previously stated, appear to be growing in favor. One of the chief questions still at issue is the best form of sprinkler or distributor, and another is the relative advisability of removing suspended matter from sewage before and after it has passed the filters.

In general, attention may again be called to the lack of comparative data for judging the relative merits and costs of different methods of treatment, as determined by the results obtained through a series of years in works operated on a practical, every-day basis. Attention may also be called to the very heavy capital charges which have been and are being incurred at many British sewage works, which must go far toward offsetting any advantages gained by rapid rates of treatment. Finally, it seems strange to an American to see so much perishable material used for filter beds, and one cannot but wonder whether this is wholly due to lack of permanent material at

reasonable prices or to some fancied virtue in the material itself. Present indications are that in the United States we shall do better to continue to use sand for our finer material, and, if coarser material is required, to employ gravel or broken stone, rather than cinders, clinker and broken brick.

PART I.

Works Employing Contact Beds for Final Treatment.

CHAPTER II.

The Sewage Works at Sutton, Surrey, and the First Double Contact Beds.

Sutton will go down in the history of sewage disposal as the place where Mr. W. J. Dibdin, at that time chemist to the London County Council, and also a member of the Sutton Urban District Council, first installed contact beds for the treatment of sewage. This was in 1895-6, but the original sewage works at Sutton were built in 1891-3, and made use of chemical precipitation, followed by broad irrigation, with small artificial filters for use when the land was not available.

The old precipitation tanks were six in number, each with a holding capacity of 50,000 Imp., or 60,000 U. S., gallons. The chemicals employed were 9 grains of lime and 2 grains of protosulphate of iron per Imp. gallon (7.5 and 1.67 grains, respectively, per U. S. gallon). The sewage farm included 28 acres, but of this only 18 were suitable for irrigation, and all of that is of a heavy London clay.

The effluent from the old, as from the present, works was discharged into the Pylbrook, a tributary of the Thames. Mr. Smith (mentioned below) stated that this effluent did not satisfy the Thames Conservency Board; that sludge pressing alone cost about $35 a week; that there was no demand for the sludge; and that the works were a nuisance. From these statements I inferred that the original works were so unsatisfactory as to give rise to a demand for some changes in the plant, and that this demand led to the modifications and final reconstruction, made in accordance with Mr. Dibdin's suggestions. Mr. Dibdin, however, has since informed me that the changes came about in quite another manner, and as he has kindly written for me an account of the whole transaction, I incorporate it here, as follows:

When the works were originally designed it was proposed to employ polarite for the filters, which were to receive the effluent obtained by chemical precipitation. In consequence of the expense of this material, namely, some £7 ($34) per long ton, Mr. Dibdin called the attention of his friends

on the Sutton Urban District Council to the experiments which he had been making at the works of the London County Council at Barking Creek in connection with this and other filtering materials, with the result that, instead of six proposed filters being constructed with polarite, two only were filled with that material, two others being charged with coke breeze and the remaining two with sand. In addition, on Mr. Dibdin's recommendation, a plot of land 130x34 ft. was excavated to a depth of 2 ft. and filled in with burnt ballast, obtained by burning the clay excavated. The result proved that these respective beds answered equally well, so far as quality of effluent was concerned; but the quantity passed by the polarite beds was less than that by the others, in consequence of the exceeding fineness of the sand in the sand layer used in the polarite beds, which beds consequently became water-logged. The coke breeze, indeed, gave the best analytic results, but in practice there was little perceptible difference. These results entirely confirmed the previous experience gained by Mr. Dibdin at the Barking Creek outfall of the London sewerage system and established the use of coke breeze and similar materials for the effective treatment of a clarified sewage. They also showed that the work done was due to bacterial action, following the primary mechanical action of the filter, as anticipated by Dr. Dupre and Mr. Dibdin in connection with their experimental investigations on the London sewage and its discharge into the River Thames, as expressed by them at the Society of Arts and the Institution of Civil Engineers in 1886 and 1887, and subsequently confirmed by the elaborate investigation of the Massachusetts State Board of Health from 1887 to 1889.

As a result of this work, in which it was found that the beds effcetually destroyed the organic matter in suspension in the partially clarified sewage, equal to about 7 grains per Imp. gallon, Mr. Dibdin suggested to the Sutton Council the advisability of trying the experiment of filling one of the precipitation tanks with coarse burnt ballast and discharging the crude sewage directly into it, on the assumption that if the particles of ballast were sufficiently large the fine solid matters in the sewage would percolate through the interstitial spaces to all parts of the bed, settle there during a proposed resting period of two hours and be left behind when the water was slowly drawn off, and so become the prey of the bacteria which would rapidly thrive in the "bed." Mr. Dibdin suggested that if this was found to be the case it would effectually solve the sludge problem and save the cost of chemicals and sludge pressing and do away with all nuisance.

The Sutton Council adopted the suggestion with immediately satisfactory results and gradually four of the chemical tanks were filled with ballast and used as *coarse* bacteria beds, the effluent from these being further purified on the fine coke breeze or ballast beds above referred to. In addition, other coarse beds were made in a manner similar to the large fine grain ballast bed; namely, by excavating the clay so as to form a shallow basin and filling this with the burnt clay; an arrangement which was found to answer equally well with the costly precipitating tanks constructed of concrete.

When Mr. Dibdin first proposed the fine grain beds, Mr. A. D. Greatorex, M. Inst. C. E., was the Surveyor to the Sutton Urban District Council and

carried out most successfully the various suggestions made by Mr. Dibdin. Later, when Mr. Greatorex was appointed as Borough Engineer to West Bromwich, where he most successfully adopted the principle of bacterial action for the purification of the sewage of that town, Mr. C. Chambers Smith succeeded him and under the direction of the Sewage Disposal Committee of the Sutton Urban District Council he has, from time to time, continued the extension of the works on the lines indicated above.

From this short recital of the sequence of events it will be seen that the suggestion and adoption of the principle of aerobic bacterial treatment of sewage at the Sutton works was the outcome of a desire, in the first instance, on Mr. Dibdin's part to save his fellow rate-payers from the extravagant burden sought to be imposed on them in consequence of the high price charged for a material proposed to be used for the filters which were to receive the usual chemical effluent. This having been accomplished, the continued personal observation of the results of his suggestions both at Sutton and at the works of the London County Council under his charge at Barking Creek and Crossness gradually convinced him that the action at work in the fine beds might be harnessed to yield yet greater results in regard to the crude or merely strained crude sewage. The result has more than justified his conclusions.

Sutton has a population of about 17,000, and an area of 1,836 acres. Water is supplied by a private company from wells in the chalk by pumping. As stated by Mr. Dibdin Mr. C. Chambers Smith is the surveyor of Sutton.

Sutton has a separate system of sanitary sewers, but as is so general with such systems, the volume of flow is materially increased by wet weather. The excessive flow is applied to one and one-half acres of osiers. Some sewage is also applied to Italian rye grass and to peppermint, chiefly for the benefit of the crops, rather than as a means of disposal.

Practically the whole sewage of Sutton comes to these works. The quantity received daily is 550,000 Imp., or 660,000 U. S., gallons. There is a high-level and a low-level outfall. Each delivers sewage at the works by gravity, but the low-level flow, which is about one-fourth of the total, had to be pumped 33 ft. to the higher part of the farm. It was necessary to continue pumping in order to put the low-level sewage into the contact beds, and subsequently into the septic tanks, but the small area and fall required for the triple contact beds recently added renders available, without pumping, a tract of land between the level of the pumping station and the brook which receives the final effluent.

At the time of my visit (March 24, 1904) one of six sets of new triple contact beds had just been put into use, but it will be simpler

to describe the works as they existed just before that time, and then to give an account of the additions.

The low-level sewage is screened through 3/8-in. bars, 3/8-in. c. to c., passed to a receiving tank covered from sight, only, with galvanized, corrugated iron, formed into arches, and then pumped to the outlet of the high-level sewer.

Originally the crude sewage, before being applied to the coarse beds, was passed through a 1/2-in. mesh screen fixed at this point. Later an automatically cleaned screen, devised by John Smith & Son, was substituted. This appears to have been continued in use until the septic tanks were established in 1900. Mr. Smith states that these tanks were added to obviate the necessity of screening, while Mr. Dibdin makes the following statement:

> The two precipitation tanks, which had continued to be used for that purpose pending the construction of a sufficient area of coarse beds to take the whole of the sewage, were employed as detritus* tanks with the view of keeping back the mineral matters and heavier organic particles, thus prolonging the life of the coarse beds by leaving only the smaller particles to enter them.

The two septic tanks have an available depth of 7 ft., including space for sludge and scum, and a combined capacity of 100,000 Imp., or 120,000 U. S., gallons, which is about one-fifth of the daily flow. The inlets and outlets are trapped. Roofs of corrugated iron, like the one just described, are provided. The works, it may be added, are on a hillside, below and not far from the outskirts of the town.

The scum on the tanks appeared fibrous; some was brown and some gray; and it was said to be about 1 ft. deep. The tanks are cleaned about once in twelve months, when the sludge and scum together usually have a depth of 3½ ft. The sludge is discharged by

*As will be seen further on, these tanks are, both in design and operation, open septic tanks, with a short period of sedimentation. Mr. Dibdin objects to calling them septic tanks, urging that such tanks require 18 to 36 hours sedimentation and that it is unfair to apply a trade name to an object or method which does not comply with the standards set by the proprietors of the object or method so named. Mr. Smith also, in my interview with him, used the term detritus tank, instead of septic tank, but in revising this chapter (see Preface) Mr. Smith took no exception to my use of the term septic tank throughout. It may be added that, as I understand it, it was originally supposed that contact beds alone, with no preliminary treatment, would be sufficient and that Mr. Dibdin is still opposed to septic tanks or any method involving putrefaction. I also understand that the septic tanks at Sutton were introduced quite independently of Mr. Dibdin's suggestions.—M. N. B.

gravity into a lagoon, and, according to Mr. Dibdin, is the cause of considerable nuisance when it is left to drain and dry.

The effluent from the septic tank passes through a brick channel to the coarse grain beds, each of which is provided with a central carrier of wood, from which there extend over about one-fourth of the width of the bed in each direction, and about 8 ft. c. to c., semicircular wrought iron or steel distributors.

The sewage is applied to the beds two or three times each day, the time taken in filling, standing full and emptying being six hours; thus giving two hours rest at three cycles and six hours at two cycles. The beds are filled within about 3 ins. of the top. The whole series of operations is performed by means of Adams automatic apparatus. This apparatus also fills and empties the fine beds, which are supplied with coarse bed effluent, and have a like period of contact. The automatic apparatus consists essentially of siphons, operated by means of air, compressed by sewage in or beneath floating boxes or domes. The manager stated that the apparatus gives no trouble by getting out of order, which is more than can be said for automatic devices generally.

The distributors for the fine beds are of wood, placed at right angles to the long side of each bed, 30 ft. c. to c.

Underdrains are provided in both the coarse and fine beds. The main drains are 6 ins. in diameter, and the smaller tributary drains are 6 ft. c. to c.

There are six coarse and six fine beds. The combined area of the coarse beds is 2,300 sq. yds., and of the fine beds 3,911 sq. yds., making 6,211 yds. altogther. This is 55,899 sq. ft., or 1.35 acres. The coarse beds have depths of 4½, 6 and 7 ft., and the fine beds are from 2½ to 3¾ ft. deep. The material composing the coarse beds is hard clinker, from 3 ins. to ¾-in. in size, from which all dust has been excluded. The fine beds, with the exception of the first one built, are of ¾ to ¼-in. coke breeze. The material in the first fine bed is smaller in size than that in the others, and is a mixture of burnt ballast (clay) and coke breeze. This bed, I found, had a surface composed of ridges and furrows, but all the other beds, both coarse and fine, had plane surfaces. The manager said that the material in this first bed had not been renewed since it was put in operation, ten and one-half years before. The fine-grained beds are forked over about once in twelve months.

The effluent from the fine or secondary beds flows several hundred yards in a shallow stream through an open channel of brick and of concrete. A number of drops in the channel, combined with the surface exposure, afford some aeration before the effluent is discharged into the brook.

I noted that the untreated sewage was an opaque, light brownish gray, more turbid than the sewage generally seen in the United States, but most of the suspended matter seemed to be finely divided. The septic tank effluent showed less of both turbidity and suspended matter. The coarse or primary beds yielded a clearer effluent, still quite opaque when seen in quantity, but comparatively free from visible suspended matter. The fine beds showed a clear effluent. There was practically no deposit on the surface of any of the beds. The past winter had been very wet, with but little sunshine. No odor was observed on any part of the sewage works.

Inquiries regarding the life of the contact beds elicited nothing in addition to the information already given, except that up to 1899 (after twelve months' use) the coarse grain beds had lost 22% of their interstitial sewage capacity, and the fine beds had lost none of theirs. It is said that the effluent from the contact beds satisfies the Thames Conservency Board, which periodically samples and analyzes the effluent.

I gained the impression that no detailed systematic records showing the operations of the beds have been kept since those given in the annual report for 1899.

A description of the additional works may now be given. The old receiving tank at the pumping station will be used hereafter as a septic tank, and a second tank, which will be covered from sight and from the wind, will also be used. Each tank will be 22x35 ft. by about 7 ft. effective depth, and the two combined will have a capacity of 63,000 Imp., or nearly 80,000 U. S., gallons. The inlets and outlets are trapped.

The sewage will flow continuously through the first and then through the second tank, and on into and through a long open channel. This channel parallels one end (22 ft.) and a side (35 ft.) of one of the septic tanks, and extends along the upper ends of the six sets of triple contact beds, making a total length of some 200 ft. The channel is 5 ft. wide, and must fill to a depth of 1 ft. before any of

the septic tank effluent can go to the coarse or primary contact bed, which it then does by means of siphons.

The three beds in each set have a uniform width of 35 ft., and their surfaces are all at the same level, but the beds diminish in width and in size of material and increase in depth from the coarsest to the finest. The arrangement can best be shown in tabular form.

Bed.	Surface dimensions.	Depth, Feet.	Size of Material, Inches.
Coarse	35 x 58	2½ to 2¾	4 to 2
Medium	35 x 48	2¾ to 3	2 to ¾
Fine	35 x 35	3 to 3¼	¾ to ⅛

The increase in depth of the beds is due to a fall of 3 ins. in the bottom of each bed from end to end, besides which there are drops of 3 ins. between beds Nos. 1 and 2 and bed No. 3 and the brook, making a total fall of 18 ins. between the upper end of the bottom of No. 1 and the brook. The area of each set of beds is 4,935 sq. ft., and the six sets will add 29,610 sq. ft., or 0.68 acre, to the old beds, making 2.03 acres in all.

The material in each bed of each set is as follows: Nos. 1 and 2, clinker; No. 3, pan breeze.

From the main supply channel extending along the upper end of the sets of beds a feed siphon inlet passes through the wall into the coarse bed, or No. 1. There is also a single inlet to each of the other beds, and that is in one corner, directly opposite a corresponding outlet, connected with the underdrains of the next preceding bed. The arrangement can best be understood after stating that each bed has a 6-in. main underdrain, laid nearly across the diagonal extending from one corner to another. On either side of the main drain there are 3-in. branches, 6 ft. c. to c. In the corner at the lower end of the main drain in the first bed there is an automatic discharging chamber, and directly over the wall is a receiving chamber in the next bed. The second main drain extends from near this receiving chamber to a discharging chamber diagonally opposite, and the same arrangement is repeated in the third bed, only the main drain here is parallel to the first main drain.

When the first bed is filled its outlet siphon comes into operation, and thus the second one is also filled. No. 3 is filled in like manner, and as soon as it is full it fills a stop-off dome air chamber until the air thus compressed is forced back through a pipe and shuts off the feed to the first bed.

I was told by the foreman that the beds already completed were being filled in about two hours, and that the contact period was about three hours. The time the beds stand full can be regulated by adjusting the rate of outflow from the full bed (No. 3) to the controlling apparatus, and the same general principle is employed to control the period during which the beds stand empty. The three beds of each set are filled nearly to the top of the contact material. Adams' apparatus is used here, as at the other beds.

Using for computation the larger of the two figures given me for volume, namely, 550,000 Imp., or 660,000 U. S., gallons a day, we have an average hourly flow of 27,500 gallons passing through detritus tanks of 120,000 gallons capacity, thus giving somewhat less than five hours in the tanks. The tank effluent is treated on 1.35 acres of double contact beds, or at the rate of about 470,000 U. S. gallons per acre per day. When the six sets of triple contact beds are completed the old septic tanks and the double contact beds will be relieved of perhaps one-fourth of the volume they are now receiving. The two septic tanks at the old pumping station have a capacity of nearly 80,000 U. S. gallons, or about half the daily volume of low-level sewage, which, I understand, is approximately 165,000 U. S. gallons. If this volume only is treated on the 0.68 acre of triple contact beds the rate per acre will be about 240,000 U. S. gallons, but the new beds are designed for a future increase in the volume of sewage, and will be constructed as necessity requires.

The cost of working the farm and treating the sewage for the years 1897 to 1904 averaged £633, or $3,076, per year, as compared with £913, or $4,437, a year for 1892 to 1896, prior to the adoption of contact beds, when the population was 3,000 less than at present and the sewage proportionately very much less, in consequence of a large number of houses not then having been connected to the sewers. Practically about double the volume of sewage, Mr. Dibdin states, is now being treated for two-thirds the former cost, including all expenses for farming operations.

CHAPTER III.

Closed Septic Tanks, Single Contact Beds and Land Treatment at Exeter.

Exeter is a Mecca for those investigating sewage disposal and its prophet is still in the flesh. To Exeter I journeyed through the charming scenery of Devonshire on a glorious April day, and there I was welcomed by Mr. Donald Cameron*, the quiet Scotchman who on March 31, 1896, introduced to Great Britain, if not to the world, what was probably the first septic tank conceived, constructed and operated on scientific lines.

I have used guarded language in writing of the St. Leonard's installation, as it was called, bearing in mind the controversies which have raged and are still in progress in America over the origin of the septic tank. It is foreign to my present purpose to enter into these controversies.†

As is generally known, the essential features of the system of sewage treatment introduced at Exeter by Mr. Cameron are (1) small grit or detritus chambers for the removal of sand and other inorganic matter from sewage; (2) covered tanks for the sedimentation and liquefaction of a part of the suspended organic matter in the sewage; (3) so-called bacterial beds, making use of ærobic bacteria to complete the process of reduction begun by the anærobic bacteria in the septic tank; and (4) automatic gear, which fills, holds full and empties the filters automatically. The bacterial beds are essentially the same as the contact beds or filters introduced by Mr. Dibdin at Sutton, with the automatic gear added, only where Mr. Cameron and his associates have been given a free hand they have generally confined themselves to single contact beds.

Exeter has a population of about 48,000 and an area of 3,158 acres. It owns water-works which draw a supply from the River Exe by pumping. Mr. Cameron was city surveyor of Exeter from 1883 until 1903, when he resigned and was succeeded by Mr. T. Moulding, the present incumbent.

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*7 Bedford Circus, Exeter, England.

†An able historical review of the subject will be found in "The Antecedents of the Septic Tank," by Mr. Leonard Metcalf, M. Am. Soc. C. E., Trans. Am. Soc. C. E., Vol. XLVI., p. 456 (December, 1901).

The main sewage works at Exeter, which I visited on April 11, 1904, receive the sewage from a population of 38,000, and are designed for a population of 47,000. A similar plant, on a lower level, was being completed at the time of my visit to treat the sewage from a population of 10,000 inhabiting the adjoining district of St. Thomas, recently annexed to Exeter.

Before describing the main works a few words may be said regarding the original St. Leonard's installation, so named because it received the sewage from a district of that name, with about 1,500 inhabitants. This small septic tank was built on the site of the present main works. No provision was made for cleaning the tank, and no sludge was taken out for five years and two months, when the liquid was pumped off and about one-third of the sludge, or deposit, as Mr. Cameron prefers to call it, was removed. I found the tank being completely emptied, after a little over eight years of service. The work was being done for and under the direction of the Royal Commission on Sewage Disposal. All the deposit will be measured and analyzed. I saw some of the deposit. It was a thick, black mass, with a greasy, inky appearance, and the particles composing it were very fine-grained. The deposit, Mr. Cameron said, was mostly at the outlet end, to which it is carried by the on-flowing current when lifted from the bottom by air bubbles.

The sewers of Exeter are on the combined plan, and some of them were built many years ago. Until the present sewage works were built the sewage was discharged into the River Exe, at various points within the city, thus necessitating the construction of intercepting sewers before the disposal works could become available. The intercepting sewers were designed to convey six times the dry weather flow, the surplus going by storm overflows into natural water courses.

Before the present scheme was adopted both irrigation and chemical precipitation had been given serious consideration, and the city some 25 years ago went so far as to buy the small tract of land now used to supplement the septic tanks and contact beds. An outfall sewer extending well down into the tidal portion of the Exe was also considered. The St. Leonard's installation was put down to test in a small but practical way Mr. Cameron's proposition for the works finally built. After this had given local satisfaction for a year or two, and attracted much attention in engineering and sanitary circles, the city applied to the Local Government Board, in 1897, for the

approval of a loan to carry out similar works for nearly the whole city. The usual inquiry was held, before two inspectors, and sanction was given with the understanding that the land already owned by the city would be used to treat the effluent from the proposed works. A loan of £42,000, or about $204,000, was finally authorized for the purchase of land, the construction of the sewage works and the cost of the intercepting sewers. The intercepting sewers were built by the city direct.

The leisurely way in which municipal contract work proceeds in England will be appreciated when I say that although the contractor for the septic tanks and contact beds began work in April, 1900, he did not complete it until January, 1901, and that the filtering material had to be put in place after that. Only 32,000 cu. yds. of excavation, 7,500 cu. yds. of concrete, two miles of distributing and eight miles of drain pipe were involved.

The contract price for the tanks and beds was £12,815, or about $62,000. The filtering material, consisting of 17,000 cu. yds. of crushed and screened clinker, cost £3,123, or about $15,200; say 90 cts. per yd. The cost of the conduit to the irrigation area was £2,000, or $9,700, and of the concrete carriers and the ditches from these £1,000, or $4,860. The land at the site of the tanks and beds cost £3,000, or $14,600. This makes a total of £22,000, while £2,000 for incidentals, engineering and superintendence brings the cost of the new disposal works up to £24,000, or about $117,000. Presumably the remaining £18,000 of the loan was spent for the intercepting sewers. The irrigation area bought in 1879 cost £3,000, or about $14,600.

The formal opening of the works took place on August 13, 1902, but Mr. Cameron informed me that the septic tanks were put into service about Christmas, 1901, and the contact beds some three months later.

The sewage comes to the works by gravity. The dry weather flow, from a population of 38,000, is given as 1,000,000 Imp., or 1,200,000 U. S., gallons, and the storm flow as only 4,000,000 Imp., or 4,800,000 U. S. gallons. Not all the sewage receives full treatment, as already explained. Both the partially and the fully treated sewage, after passing over the land, are discharged into the River Exe. The works are close by the river, which is tidal nearly to the foot of the irrigation area. The river water is ponded by millers in the summer,

but the ordinary summer flow may be taken as 7,000 cu. ft. per min. The flow went down to 5,000 cu. ft. per min. one summer, and although the river then received untreated sewage from 30,000 people the albuminoid ammonia in the river water below the outlet was only 0.4 parts per 100,000, as compared with 0.3 above the outlet.

The sewage is discharged from the gravity outfall sewer into three grit or detritus chambers, each 6 ft. in average width, 18 ft. long and 3 ft. deep, with their largest dimensions parallel to the direction of the flow of the incoming sewage. The grit is removed from these chambers about once a month in winter and less often in summer, when the rainfall is not so great. The grit is simply thrown into a heap.

There are six covered septic tanks, each 36 ft. wide, 180 ft. long and 8½ ft. deep below the springing line of the roof, but with a normal working depth of only 6½ ft. There are four submerged inlets to each tank. For outlets horizontal submerged slotted cast iron pipe are placed 3½ ft. below the springing line of the roof arches. These outlets discharge into an effluent channel, which in turn supplies effluent distributing channels leading to the alternating gear valve chambers which automatically control the closing of the beds. The effluent channel also connects with an overflow weir at one corner of the group of septic tanks. The top of this weir is about 2 ft. above the low water level of the septic tanks, thus affording storage for the first portion of the storm water. At least this was the original plan of the works, which were designed to treat up to 2½ times the dry weather flow in the septic tanks and on the filters and 3½ times additional in the tanks and on the land. I was told that from 1,500,000 to 2,500,000 Imp. or from 1,800,000 to 3,000,000 U. S. gallons a day were the maximum amounts receiving full treatment, and that 14 hours is the period of detention in the septic tanks for the dry weather flow.

The septic tanks can be worked continuously or any one can be cut out, according to the rate of flow. The deposit is removed by means of V-shaped slots across the outlet ends of the tanks and into chambers.

The original plan contemplated only infrequent removal of sludge from the tanks, which was to be effected without drawing off the sewage, by means of the grooves just mentioned. I neglected to enquire how often, if ever, these outlets had been used, but I was told that about March 1, 1904, a portable oil engine and pump had been secured and that there had been initiated the practice of pumping

the deposit once a month from the chambers already mentioned. The first deposit thus removed, Mr. Cameron said, resembled Chinese ink, ground ready for use, and was simply discharged alongside a fence and left there.

There are twelve contact beds, each about 1,000 sq. yds. in area, thus making a total of about 2½ acres. The contact material has a depth of 4 ft. and with the exception of 6 ins. of gravel at the bottom of six beds, it is mostly composed of furnace clinker between 1 and ¼-in. in size. The first clinker used was from ¾ to 1-in., which Mr. Cameron said would be satisfactory when broken from a hard clinker like that afforded by refuse destructors; but this early clinker contained too much fine stuff.

The septic effluent is distributed by means of half round tiles, quite close together, sunk flush with the surface of the beds. The underdrains are of 3 and 4-in. agricultural pipe, laid 3 ft. c. to c. and discharging into a concrete main drain beneath the main carrier, in the space between the beds.

The beds are worked in groups of four, one of each group being cut out for rest about two days, the remainder doing the work. Each of the beds in use on a given day is filled, stands full and is discharged in a total of three hours. This is repeated three times each day, leaving 15 hours out of the 24 for resting and draining.

The alternating valve gears are worked by means of buckets and counterweights, placed on levers, and by float valves and chambers, the buckets and float valves being operated by the sewage.

The principal work done on the beds consists in keeping down grass and weeds, chiefly in winter, skimming off the deposit along the distributors, and lightly raking the surface of the beds. I noted that one bed was pretty well covered with grass, and was told that it had not been cleaned since October, 1903, or for six months. The winters in the South of England, it hardly need be said, are quite unlike those in our New England and other Northern States.

The city owns 16 acres of grass land for the land treatment of the sewage. About 3½ acres of this is located near the contact beds, and receives the storm overflow. The greater part of the grass land is a half mile or so further down the river, is known as Ducks' Marsh, and to it the contact bed effluent is conveyed in a closed conduit, discharging into four open channels of concrete, laid on contour lines. From these channels the effluent is led over the field in ditches. The land is neither graded nor underdrained, but some of it is underlaid with

gravel, and a fourth of an acre of this has been provided with open-jointed pipes for sub-irrigation. Some of the ditches extend virtually to the slough at the lower corner of the field, through which the land effluent reaches the river. The water in this slough appeared to be about the same color as that in the weir. This land is leased by the city to a man who pastures bullocks on it in the winter and cuts grass from it in the summer.

I was told that only two men are employed to operate the septic tanks and contact beds. I detected no odor anywhere. Mr. Cameron appears to have virtual if not actual control of the works, although no longer city surveyor. He remarked to me, before I left him, that covering septic tanks is not essential to the process, but that it is desirable wherever the climatic variations are marked or the tanks are located near dwellings.

CHAPTER IV.

Grit Chambers, Septic Tanks, Contact Beds, Aerating Pool and Land Treatment at Yeovil.

Although Yeovil is a small borough its sewage is not a simple one. This is due to the glove and other leather industries at Yeovil, which produce a strong sewage containing leather tanning and dyeing wastes, arsenic, hair and scraps of hide and leather. The sewage works include grit chambers, closed septic tanks, double contact beds, with an aerating pool between, and land treatment. A small experimental installation was opened in September, 1896, but the present works were not put in operation until early in 1903.

The population tributary to the Yeovil sewage works is estimated at 14,000. The borough owns its water supply. The water consumption is about 28 Imp., or 34 U. S., gallons per capita. The sewers are on the combined plan. The sewage reaches the works by gravity, except for about 30,000 Imp., or 36,000 U. S., gallons, which is delivered by an Adams sewage lift. Although classed as a water closet town the closets in the older houses, being perhaps half of the whole, are flushed by carrying water to them in buckets. The dry weather sewage flow is given as 500,000 Imp., or 600,000 U. S., gallons, and the storm flow as 5,000,000 Imp., or 6,000,000 U. S., gallons.

I was shown about the Yeovil works on April 11, 1904, by Mr. Oddy, the borough surveyor. The local engineering responsibility

for these works, however, rests on Mr. W. K. L. Armytage, Borough Surveyor of Yeovil from 1891 to 1902 or 1903, and the detailed plans were made by the firm of Cameron, Commin & Martin.

With the exception of some kind of lime treatment, subsequently abandoned, the sewage of Yeovil was discharged untreated into the River Yeo until the present works were built. In 1896 the borough was ordered by the County Court, on application of the Somerset County Council, to treat its sewage. In September, 1896, a closed septic tank with a capacity of 20,000 Imp., or 24,000 U. S., gallons, supplemented by double contact beds, was put in operation to test the method which had then been on trial for a few months at Exeter. At a Local Government Board hearing conducted by Mr. F. H. Tulloch, M. Inst. C. E., on March 20, 1900, plans for complete works were submitted, and these were supported by testimony, including analyses, by Messrs. W. J. Dibdin, Samuel Rideal and Gilbert J. Fowler, all well known British chemists. All agreed that the experimental works, which had then been in operation some 3½ years, had given satisfactory results, and that the same system on a larger scale, supplemented by land treatment, would be a safe method to adopt for the sewage of the whole borough. In course of time the plans were approved, and early in 1903, as already stated, the works were put in operation.

It is interesting to note that the dry weather flow of sewage was based on the per capita water consumption of the time, with no allowance for a future increase in the unit rate, and that sewer gagings made in 1899 showed the following results: April, 468,000 Imp., or 682,000 U. S., gallons, of which 385,000 U. S. gallons was classed as night flow (night hours not defined); September, 380,000 U. S. gallons. At the time of the April gaging it is stated that "there was a lot of stream water running into the sewers."

The population provided for in the estimates was 14,000 (for 30 years thereafter), which at 28 Imp., or 34 U. S., gallons per head gave a volume of 392,000 Imp., or 470,000 U. S., gallons. The works were designed to treat sewage and storm water up to three times the dry weather flow, or 1,410,000 U. S. gallons, in the tanks and contact beds, and an equal volume of storm water flow on a special area, all in accordance with regulations previously established by the Local Government Board. There are three grit chambers and five septic tanks. Each of the latter is 14 x 200 ft., with a mean low water depth of 6 ft., a depth of 7½ ft. to the springing line of the roof arches, and a further

depth of 6 ins. before the storm overflow would come into operation. This gives, at the low water level, a total capacity of about 500,000 U. S. gallons, or a little in excess of the dry weather flow. In times of rain the septic tanks would operate at an increase of capacity a little less than one-third of that given.

There are 12 primary and 12 secondary contact beds, each 6½ x 64 ft., giving a total area of 10,670 sq. yds., or 2.2 acres, for a daily dry weather flow of 600,000 U. S. gallons. As half of this area was considered to be ample for the dry weather flow it was proposed that the latter should have double treatment.

Three grit chambers, each about 4 x 12 ft. in plan, are provided at right angles to the inlet channel to the septic tanks. Each tank has four manholes; one close to each end, and one a third of the distance from either end. A 12-in. sewer pipe, extending up through each manhole and capped, was provided.

The distributors on the surface of the beds are of half tile, 8 ft. c. to c., running clear across the beds. The surface of all the beds is forked over once in two weeks or so to keep down weeds and to loosen the material, which is crushed furnace clinker, 3 ft. deep in the upper and 2 ft. deep in the lower or secondary beds.

Between these two sets of beds, receiving the effluent from the first, is an aerating pool, some 40 x 160 ft. in plan, with 6 ins. of broken stone in its bottom, above which is 9 ins. of sewage effluent. The liquid passes across the smaller dimensions of this pool.

The dry weather flow passes through the two sets of beds. As the flow increases in wet weather a portion of the septic tank effluent is diverted to the lower beds, which, according to the original design, still receive the effluent from the first beds. When the storm flow increases sufficiently the lower beds receive septic effluent only. All effluent from the upper beds not sent to the lower ones goes to the high level irrigation area. The flow from the lower beds, whether single or double contact effluent, goes to the low level irrigation area.

The storm water, above the capacity of the septic tanks and contact beds, is sent to filter beds of broken clinker, over which it is distributed by means of wood troughs. The past winter had been wet, and it had been necessary to shovel deposits of sediment from the storm water beds. I saw many wagon loads of this deposit which had been dumped in an adjoining private field for use by a farmer.

The area for land treatment is separated from the other part of the works by private land beneath which sewage is conveyed in a

closed conduit. Like the irrigation area at Exeter, this is neither graded nor underdrained, and was provided to satisfy the Local Government Board. Mr. Oddy said that drainage at Yeovil was prohibited, the theory being that the land would absorb the sewage. Both the high and the low level main carriers are open brick channels, from which at intervals of about 25 ft. a single length of pipe discharges the bed effluent into ditches at right angles to the carriers. The River Yeo flows along one side and end of the irrigation area, and at the time of my visit was some feet below the surface of the land. Mr. Oddy said, however, that the low-level land had been flooded during the past winter, which was unusually wet.

The condition of the works on April 11, 1904, indicated either that the system was not suited to the character of the sewage or that the works were not being properly operated. The latter was admitted to be the cause of a part of the poor condition of the works, and was attributed to the fact that Mr. Oddy had recently been sick and had not been able to give the works close attention.* Mr. Oddy, however, was of the opinion that the septic tanks had never shown the results readily obtained in the experimental installation.

The crude sewage, as it entered the grit chambers, was of a dark, grayish-brown color and looked very strong. I was informed that the grit is removed from these chambers once a fortnight and buried, but when I saw them they were nearly full of deposit.*

The effluent from the septic tank, as seen in bulk, seemed almost as dark colored as the crude sewage, but it was not so brown and contained less visible suspended matter. In a test tube this effluent had a milky or cloudy appearance.

The septic tanks have never been emptied (but had been in operation only a year). Mr. Oddy had every manhole removed while I was with him and made rough measurements of the deposit in the tanks, using a pole for the purpose. At the inlet ends and some 65 ft. beyond the deposit extended practically to the sewage level, there being only three of the ten manholes where there was as much as 12 ins. of sewage above the deposit. The deposit was rather dense, and at the

*Mr. Cameron has since written to me as follows:

"In consequence of Mr. Oddy's illness the works for the whole twelve months (since they were put in operation) received practically no attention, but notwithstanding this the filtrate, according to the report of the Analyst of the County Council, was most satisfactory, giving results superior even to those obtained by the experimental installation. For a whole twelve months nothing was removed from the grit chambers."

inlet of one of the tanks (the only one thus examined) a bucket full of the deposit contained much hair and many scraps of leather. At the third row of manholes, 135 ft. from the inlet end, the deposits ranged from 1¼ to 3½ ft. in depth, and were semi-liquid in character, while in the fourth row, or close by the outlet ends of the tanks, the deposits were from 1 to 1½ ft. deep and still more liquid in character. Bringing all the gagings together, we have the following depths in feet and inches:

Manhole	Tank No.				
No.	I.	II.	III.	IV.	V.
1	6—0	7—0	7—0	7—0	6—0
2	7—0	7—0	7—0	7—0	6—0
3	1—3	2—6	2—3	2—6	3—6
4	1—0	1—6	1—3	1—3	1—6

With the exception of small patches at one or two manholes near the outlet end no scum was observed during the inspection. Mr. Oddy said that there had been no scum on these tanks since they were put in operation, although scum formed on the experimental tank. He was of the opinion that the tanks were effecting sedimentation only. The operations of the tanks were not being gaged by chemical analysis.

The condition of the effluent from the septic tank has already been mentioned. As seen in a test tube the filtrate from the upper contact beds was nearly clear and almost free from visible suspended matter, and that from the lower beds showed still further improvement. The surfaces of both sets of beds were in good condition.

Portions of the main carrier to the high level area and the upper ends of the ditches leading therefrom were covered with scum. Some of the scum on ditches had dried and flies abounded where the sludge was wet.

The V-shaped main carrier to the low-level beds contained 6 to 9 ins. of fine deposit in its upper end, and its lower end was covered with an inch or so of scum. The upper ends of the distributing ditches were also covered with scum. The land, particularly at the lower end, was water-logged, and water was flowing from it over and down the bank into the river. There was a trench 4 or 5 ft. deep along the side of the land furthest from the main carrier, and water was flowing from this to the river.

Laborers at the sewage works are paid three shillings, or about 75 cts., a day for ten hours' work. As a rule only one man is em-

ployed, but he has assistants occasionally. He goes to the works every Sunday morning, but does not remain there unless there is a heavy storm flow, and receives no pay for his visit unless he has to remain on the grounds.

In judging these works it is only fair to them and to Mr. Oddy to bear constantly in mind that Mr. Oddy did not assume charge of them until after they were completed, and that he has suffered from illness. As to the design of the works Mr. Oddy made no criticism further than that he considered the land treatment unnecessary, and that the automatic dosing apparatus, while a mechanical success, took no cognizance of the quality or strength of the sewage. The latter opinion has been expressed to me by a number of other men having to do with sewage works in Great Britain, and is to my mind an obvious weakness in automatic dosing. On small works one man can readily turn the sewage from bed to bed, and on large ones the beds can be dosed in groups, from a common valve chamber, thus reducing the necessary attendance, while in either case the dosing may be varied in accordance with the strength of the sewage and the condition of the beds.

CHAPTER V.

Closed Septic Tanks, Glass Covered Aerating Channel and Single Contact Beds, at Barrhead, Scotland.

One of the oldest septic tank installations in Great Britain is at Barrhead, Scotland, a small town near Glasgow, having a population of about 10,000. I visited this plant on April 19, 1904, under the guidance of Mr. A. W. Bryson, Borough Surveyor. Mr. Bryson assumed office since the sewage works were built. The plans for the works were made by the firm of Messrs. Cameron, Commin & Martin.

Barrhead is a water closet town, with perhaps a hundred old-fashioned privies still in use. The sewers are mostly on the separate system. A storm overflow is provided. The works are now treating about 420,000 Imp., or 480,000 U. S., gallons a day.

The sewage arrives by gravity at two grit chambers, each 5x18 ft. by 8 ft. deep. The deposit in these chambers is stirred frequently during the day, so only the heavier matter is retained. The chambers are cleaned once in 18 months.

Each of the four covered septic tanks is 18x100 ft. by 8 ft. deep, and has two inlets and two outlets. I was told that they have not been cleaned during the six years they have been in operation; that there is no deposit at their inlet end; and that the sedimentary matter at the outlet end is only 6 to 8 ins. deep. The combined capacity of the tanks, assuming the full 8 ft. of depth to be available, is about 360,000 Imp., or 430,000 U. S., gallons, or a little less than the daily flow of sewage.

The tank effluent flows into a V-shaped aerating channel 30 ft. long, which overflows on either side into a second channel, extending some distance to the automatic dosing apparatus. Both channels are covered with a double-sloped glass roof, open at its two gable ends. The aerating channel is cleaned once a week.

There are eight single contact beds, each 54 ft. sq., composed of unscreened clinker. Half tile distributors, about 9 ft. c. to c., are laid in the tops of the beds. The upper layer of the beds is forked over about once a fortnight, and the deposit each side of the tile distributor is cleaned off. The top of the beds lies up very light and spongy, compressing noticeably under the feet. The filtering material has never been renewed. The combined area of the beds is 23,328 sq. ft., which for 480,000 U. S. gallons a day gives an average rate of a little less than 900,000 gallons an acre.

For underdrains agricultural drain tiles, about 3 ft. c. to c., are used. The effluent flows directly to Levern Burn, a small stream, as did the untreated sewage before the works were built.

In a test tube the effluent from the septic tank was comparatively clear, except for small black spots. For a septic effluent it also looked remarkably clear in bulk. The effluent from the beds appeared clear in a test tube, with scarcely any visible sediment. At a depth of 6 ins. at the outlet the effluent in bulk also appeared clear.

The total cost of these works, including about 1,500 ft. of outfall and engineering fees, was about $25,000. The borough paid some $20,000 additional for eleven acres of land, only two of which have been utilized by the works. The only operating expenses, I was told, are £1, or $4.86, a week, paid to the caretaker. Everything about the works was neat, and flower beds added to the generally favorable impression made upon the visitor.

CHAPTER VI.

The New Sewage Works at Manchester.

If an American wished to visit a large sewage works in Great Britain, where open septic tanks and contact beds are used, and could visit but one such plant, I would advise him to go to Manchester. My reason for this is that the problem at Manchester is being solved very much as American engineers and chemists would be likely to solve a similar one. The general scheme having been decided on, the works are designed to effect the desired results in the simplest manner and at the lowest cost consistent with efficiency and durability.

The system of treatment adopted at Manchester in 1900 is (1) open septic tanks, with settling tanks for the storm flow; (2) double contact beds; (3) treatment on land; (4) special filters for storm water flow. The final effluent is discharged into the Manchester Ship Canal and the sludge is taken to sea in a large tank steamer. Thus far nothing has been done toward constructing the second contact beds and preparing the land treatment area, but most of the land for that purpose has been acquired. Good progress is being made on the other parts of the works.

The design of the works is based on the conclusions drawn from the well-known experiments conducted in 1898-'99 under the direction of Mr. Baldwin Latham,* M. Inst. C. E., as engineer; Prof. Percy Frankland,† as bacteriologist, and Prof. W. H. Perkin, Jr.,‡ as chemist. The works are being carried out by the Rivers Department, Manchester, to which Mr. James P. Wilkinson,§ Assoc. M. Inst. C. E., is engineer, and Dr. Gilbert J. Fowler¶ is superintendent and chemist. I am indebted to both these gentlemen, and particularly to Dr. Fowler, for courtesies extended me during my visit to Manchester in April, 1904.

Manchester has a population of about 545,000 and an area of 13,654 acres. It appears, however, that the populations and areas

*Victoria St., Westminster, S. W.
†Birmingham University, Birmingham.
‡Manchester University, Manchester.
§301 Cathedral St., Manchester.
¶Broad Oak, Urmston, near Manchester.

connected with the sewers are some 574,000 and 11,600, respectively, including some outlying districts. Not long ogo the city introduced a new gravity water supply from Lake Thirlmere. The sewers are mostly on the combined system. Pail closets are being replaced by water closets, but on March 31, 1902, there were about 80,000 pail and only 46,000 water closets.

The average total daily flow of sewage delivered at the works for the twelve months ending March 30, 1904, was 35,457,000 Imp., or 42,548,000 U. S., gallons. The maximum daily flow was 113,815,000 Imp., or 136,578,000 U. S., gallons, and the highest rate recorded (9 p. m. to 10 p. m. September 10, 1903) was at the rate of 174,756,000 Imp., or 209,707,000 U. S., gallons an hour.

The average daily per capita volume of sewage for four-week periods ranged from a minimum of about 42 Imp., or 51 U. S., gallons for the four weeks ending June 17, 1903, to a maximum of 93 Imp., or 102 U. S., gallons for the four weeks ending November 4, 1903. Taking the former as the dry weather flow and the tributary population as 574,000, we have a total per day of about 24,200,000 Imp., or 29,000,000 U. S., gallons.

Rain was recorded on 219 days during the year, and the rainfall was some 38 ins., which was above the average for recent years. The sewage flow is automatically recorded in the main sewer, a correction derived from direct measurements being applied to the flows calculated by formula from the recorder diagrams.

The sewage works are located on the Manchester Ship Canal, at Davyhulme, about five miles from Manchester. The original works were put in operation in the spring of 1894, and treated the sewage by chemical precipitation, using lime and copperas as agents. It was foreseen that the effluent could not be discharged into the already-polluted Ship Canal without creating a nuisance, and in the original scheme land filtration was contemplated. The necessary area, however, was found to be excessive, and after rceiving many complaints from the Mersey and Irwell Joint Committee, the City Council decided in May, 1898, to enter upon the experiments already mentioned. A valuable report on the experiments was made in the latter part of 1899, and many additional data, based both on experimental and working tests, have been published in the annual reports of the Rivers Department issued since that year.

The experiments included the treatment of both settled and raw sewage by single, double and triple contact beds; raw sewage in

an open septic tank, followed by one or more contact beds; raw sewage in a closed septic tank, followed by one contact bed, and the treatment of storm water.

It should be added that as early as 1895 experiments were started with effluent from the precipitation tanks applied to filters built after designs by Sir Henry Roscoe, and that these experiments are still being continued, the results affording useful information as to the permanence of contact beds.

The main conclusions of the experiments of 1898-'99 were that the best system of treating Manchester sewage was by screening, anaerobic action in the septic tanks, and oxidation by means of contact beds. A satisfactory purification, it was then held, required more than one contact, although the effluent from one contact was found to be non-putrefactive. There was found to be practically no difference between the effluents from the open and closed septic tanks.

The plans for the new works now being carried out were endorsed by the City Council in September, 1900, and have also been approved by the Local Government Board. The complete scheme is designed to deal with a maximum of 126,000,000 Imp., or 151,000,000 U. S., gallons a day, all this quantity to be passed through either the septic or the settling tanks, and the first half to be applied to double contact beds, while the second half would go to special storm water beds only. The volume in excess of 151,000,000 U. S. gallons would overflow to the Manchester Ship Canal, untreated.

The character and extent of the rearranged and new works may be briefly stated as follows: Catchpits, rough screens, automatically cleaned medium and fine screens, and chain bucket dredgers for cleaning the catchpits; 4 settling tanks for storm water and 12 open septic tanks with a combined holding capacity of about 25,000,000 Imp., or 30,000,000 U. S., gallons; 46 acres, net, of first contact beds, in 92 beds of one-half acre each; 27 acres of storm water filters; a conduit, mostly open, about 2½ miles long, with a carrying capacity, at 3¼ ft. depth, of 73,000,000 Imp., or 87,600,000 U. S., gallons a day; 46 acres, net, of second contact beds, in half-acre beds, and 100 acres of irrigation area.

The city already owned 176½ acres of land at Davyhulme, and has since acquired 7 acres additional. It secured authority from

the Local Government Board to buy 213 acres of land further down the canal for its second contact beds and land treatment area, together with 82½ acres on the frontage of the canal for the conduit between the first and second contact beds. This land is likely to increase in value, and its purchase prevented claims for severance.

The first parts of the new work to be carried out were the catchpit, screening and dredging apparatus, which were put in use in January, 1900. In May, 1901, sewage was first passed through two of the septic tanks, remodeled from the precipitation tanks. Sewage, after passing through the tank used as an experimental septic tank, was applied to some of the single contact beds in January, 1901, and settled sewage was passed on to some of the storm water beds in July, 1902. As rapidly as portions of the new works would permit, the volume of sewage treated chemically has been diminished, until in April, 1904, only some 40% of the dry weather flow was being treated, a portion of the effluent obtained passing on to the storm beds. On the same date 6 of the 11 precipitation tanks had been converted into septic tanks, and 3 of the 5 new septic tanks were under construction; about 34 out of 46 acres of first contact beds had been completed or were being prepared, and the entire storm water area of 27 acres was in use. Nothing had been done on the second contact beds, the land treatment area and the conduit leading thereto. In fact, it is hoped that when the full complement of tanks and first contact beds are in use the effluent will be so satisfactory that any further treatment required can be effected on a limited area of beds near the present outfall, the Carrington and Flixton area being reserved for future developments in accordance with the increase in the population of Manchester.

All sewage coming to the works first passes through a coarse screen consisting of 4½x1-in. bars, with 6-in. spaces between them. It then goes through a second screen, 37 ft. long, in three sections, each of which can be worked independently. The bars of this screen are of ⅜-in. iron, set to give 1¼-in. openings. They are cleaned automatically by a rake or fork consisting of teeth or tines attached to channel iron bars, fixed, in turn, on an endless chain, moving at the rate of 1½ ft. per sec. As the teeth or tines pass over the sprocket wheel on which the endless chain runs a brush sweeps the screenings into a wrought iron channel. The brush "is fixed

on a shaft actuated by a lever and counterweight for reversing the motion."* A squeegee is used to clean the wrought iron channel, and the screenings are carted away and subsequently burned in a specially designed destructor. The third or fine screens are similar to the first, except that they are composed of 3/8-in. bars, with a space of 1/2-in. between them.

The medium and fine screens are in duplicate, and between each set of screens, on either side, is a catchpit, in the form of a hopper. The deposits in these pits are removed by steel elevator buckets, 16x8 ins., x 8 ins. deep, with semicircular bottoms, the buckets being attached to endless chains. Perforations in the buckets afford drainage to the material as it is being removed. The buckets are emptied into a metal channel and finally delivered into wagons. Some 70 or 80 long tons of refuse per week are removed by these buckets.

Each of the old precipitation tanks was 100x300 ft., x 6 ft. average depth, and had a holding capacity of 1,350,000 U. S. gallons. In converting these into septic tanks the effluent weirs are raised 14 1/2 ins., thus increasing the capacity to about 1,630,000 U. S. gallons each, and also increasing the available head. When the new tanks are completed there will be eight in a row, on either side of a roadway. The four central tanks will be used as settling tanks for the storm flow, and may also be used, it is probable, for night flow. The aggregate holding capacity of the twelve septic tanks will be about 19,550,000 U. S. gallons, and of the four storm water settling tanks about 5,400,000 gallons, thus giving a grand total of about 25,000,000 U. S. gallons.

The sludge from the chemical precipitation tanks is pushed from the tanks by hand into channels leading to ejectors, and by the latter it is delivered to a couple of storage tanks near the Ship Canal. From these tanks it flows by gravity into a sludge steamer having a carrying capacity of 1,000 long tons, which conveys the sludge beyond the Mersey Bar. This steamer was put into service in December, 1897, prior to which it appears that the sludge was pressed. In 1902-'03 the steamer made 181 trips, running a total of 22,263 miles, and conveying some 223,000 long tons of sludge.

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*"The Treatment of Manchester Sewage," by Gilbert J. Fowler and James P. Wilkinson. By authority of the Rivers Department, Manchester, July, 1902.

The 46 acres of first contact beds are laid out in two groups of 20 acres each and one of 6 acres, and are supplied by main channels 18 and 16 ft. wide and subsidiary channels 6 and 5 ft. wide. Beneath the latter are the main effluent channels, thus economizing both land and cost of construction. The beds, with few exceptions, are uniform in both size and shape; and being ranged on either side of the supply channels, with inlets and outlets at the center of the side of the bed, the beds can, as a rule, be operated in pairs.

The distributing chambers are semicircular in plan, and from them the tank effluent flows over a concrete wier into radial channels, or grips, cut in the surface of the beds and banked.

The channels are about 2 ft. wide and 1 ft. deep, so that with the banks forming them they cover a large part of the area of the beds. They are formed of finer material than that composing the beds proper, thus arresting some of the suspended matter in the tank effluent. The grips are scraped about once in two weeks, and every six weeks an inch or so of fine material is added.

The contact material is screened furnace clinkers, about 40 ins. deep. The coarser clinkers are placed over and between the effluent drains. The beds have a fall of some 2½ ins. in their length of about 135 ft., and a ridge half-way between each radial drain facilitates the drainage still further.

The beds have a 6-in. concrete floor. In this the drains are formed, being semicircular channels, with a rebate on either side, at the top, for receiving perforated tile covers which are 2 ins. in thickness.

The radial drains converge into circular drains concentric with and outside the distributing chambers. Manholes are built at the outer ends of the radial drains.

To economize space the beds are separated by concrete walls, instead of earth embankments.

The flow of sewage to the various beds, with the exception to be noted, is controlled by hand. The size and grade of the supply channels permits two beds to be filled at one time. One man per shift attends to about six beds. A scheme was worked out for electrically operated apparatus, controlled from a central point, but estimates showed it to be too costly and liable to be affected by the fumes and gases arising from the sewage. Moreover, neither Dr. Fowler nor Mr. Wilkinson favors absolutely automatic dosing apparatus, believing that human judgment is essential to the best results

in the dosing of filter beds. A semi-automatic dosing apparatus is being tried on one bed. It is a modification of the electric apparatus, described above, which was designed by Mr. Wilkinson and Glenfield & Kennedy, of Kilmarnock, Scotland, and was manufactured by the latter. It is put in operation by throwing a hand lever. When the bed is full the valve closes automatically. After any desired period of contact the outlet valve, which is controlled by time apparatus, opens automatically. The throws of the lever operating the filling valve are recorded by a counter.

With the semi-automatic apparatus described the human element is introduced at the one moment when it is needed in the whole cycle of operation.

Mr. Wilkinson has installed a modified Venturi meter for one pair of beds, arranged to record the flow to each bed of the pair. He would like to provide meters for, say, one-fourth of the beds in each group.

The 29 storm water beds have an average area of nearly an acre each, the total area being 27 acres. They are composed of 2½ ft. of unscreened clinkers, the coarser clinkers being placed around and over the drains. To maintain the beds in good condition between storm flows they are used between times as contact beds. They are designed to operate at a maximum rate of 500 Imp., or 600 U. S., gallons per sq. yd., which is about 2,420,000 Imp., or 2,900,000 U. S., gallons an acre. In times of storm flow the sewage may be ponded to a depth of 6 ins. on the beds, after which bell-mouth overflows on the outlets come into operation and continuous filtration begins. Under this plan each bed will receive about 360,000 Imp., or 432,000 U. S., gallons before it begins to discharge, which is 10,440,000 Imp., or 12,528,000 U. S., gallons for the whole area. This, combined with the four storm water tanks, would give a total storage of about 17,500,000 U. S. gallons, equal to about five hours' heavy rain, at the maximum rate specified for treatment as storm water, exclusive of the volume being treated on the contact beds.

The storm water beds rest on the natural ground surface, which is generally a heavy clayey marl. Where needed a layer of concrete has been used. The sub-drains are of brick, with open joints, laid on concrete and covered with tiles laid with joints and cemented down. Most of the beds have two inlets, after leaving which the sewage finds its own way over the surface of the beds.

The second contact beds, as designed, were similar to the first contact beds, except that the material was finer. Nothing having been done toward the preparation of these, or of the irrigation area, the descriptions of each already given will be sufficient.

In general, concrete is the material used throughout where masonry is required, except that brick is used for the walls of the new sedimentation tanks.

The capital cost of the works at Davyhulme up to the time of beginning the changes to the so-called bacterial system, but including the catchpits and automatic screening apparatus, was nearly £230,000, or about $1,100,000. This sum includes the 176½ acres of land at Davyhulme. The total estimated cost of the new works was £487,000, or about $2,337,000, inclusive of purchase of land.

The preliminary estimates made by an advocate of a long outfall sewer, instead of the works now being carried out, placed the cost of contact beds at £5,500, or nearly $27,000, per acre. Thus far their average cost has been less than £3,000 ($14,580) per acre. The storm water beds have cost about $7,300 per acre.

No small factor in the reduction of the cost over the preliminary estimates has been the saving in material and labor effected by using less massive and elaborate construction than is characteristic of so much engineering work in Great Britain. It seems to me that a still further saving might have been effected, apparently without detriment, by omitting the concrete bottom from the first contact beds as well as from the greater part of the storm water filters.* This, however, would have been counter to the well-nigh universal practice in England.

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*In revising my draft of this chapter Mr. Wilkinson submitted the following comment on the foregoing remarks:

"We tried omitting the concrete bottom from the floor of one of the first contact beds; but found that the ground was too porous, and it was not considered desirable to adopt the practice generally. The concrete floor was not put in over one-half of the storm water filters; over the other half it was necessary owing to the land having been underdrained for filtration, and to the subsoil being of a wet, silty and unstable character."

CHAPTER VII.

Sedimentation and Single Contact at Oldham.

The Oldham sewage works combine sedimentation tanks with single contact beds and in some features are like the works being carried out at Manchester. This resemblance is not surprising in view of the proximity of the two places and the lead Manchester has taken in both the experimental and practical work of sewage treatment. Moreover, the chemist in charge of the Oldham works since the middle of 1902, Mr. A. H. Valentine,* was formerly an assistant to Dr. Gilbert J. Fowler, Chemist and Superintendent of the works at Manchester. For some four years the Oldham works were operated as a chemical precipitation plant.

Oldham is the principal cotton manufacturing town of England, with a population of about 140,000 and an area of 4,729 acres. It owns its water-works, which draw a gravity supply from the high moorland separating Lancashire from Yorkshire. It also owns refuse destructors, electric lights and tramways and can show many other evidences of municipal enterprise. Mr. E. C. Foote is surveyor of Oldham. Dr. J. B. Wilkinson is the medical officer of health, and he has general control of the sewage works.

The sewers of Oldham are on the combined plan, and most of the sewage reaches the works by gravity. The normal dry weather flow is 2,500,000 Imp., or 3,000,000 U. S., gallons, and the ordinary wet weather flow 4,000,000 to 5,000,000 Imp., or 4,800,000 to 6,000,000 U. S., gallons, while at times the flow reaches 25,000,000 Imp., or 30,000,000 U. S., gallons. The flow, as is so rarely the case anywhere, is measured by an automatic recording gage. The trade wastes in the sewage are small in amount, and are mostly fat from tripe works, lubricating oil from large iron works, and a small amount of waste from the cotton mills and their adjacent "lodges."† Up to the close of

*Laboratory, Oldham Corporation Sewage Works, Foxdenton Lane, Hollinwood, Oldham.

†These lodges change the character of the sewage somewhat, rather than add to it, as may be seen from the following description of them kindly furnished to me by Mr. Valentine:

"Lodges are small reservoirs adjacent to all cotton mills for the storage of water. For purposes of economy, the majority of the mill owners take their water from the sewers in the early hours of the morning, when the sewage is at its weakest, roughly strain it and send it into the lodges for use subsequently in the boilers and condensers. After some months a lodge is cleaned out, generally on Friday night or Saturday afternoon, and in this way a large amount of evil smelling black liquid sludge is sent down the sewers."

1902 there were 2,598 regular water closets, 8,856 waste water closets and 983 trough closets connected with the sewers. The degree to which the town seems to be committed to the very questionable practice of allowing water closets to be flushed with sink and other waste water is partly shown by the fact that only 151 fresh water closets were added in 1902, as compared with 3,260 waste water closets and 321 trough closets. It appears that for the most part the water closets, of whatever type, are replacing pail closets. The effect of the change upon the strength of the dry weather sewage, it is said in the annual report on the works for 1902, was marked, and with the increase in the strength of the sewage the sludge became more difficult to press, being greasier and clogging the filter cloths more. For this reason a part of the sludge in July and August, 1902, was pumped onto land without treatment, and at the time of my visit, in April, 1904, a considerable portion of very thick sludge from two large sludge storage tanks was going the same way.

All of the sewage is passed through fine bar screens and a grit chamber. The screens are cleaned occasionally by mechanically driven brushes, on an endless chain, and bucket elevators are also used occasionally to dredge the deposit from the chamber.

All the screened sewage goes to twelve tanks, one of which has been converted into an experimental closed septic tank and another is normally out of use for cleaning, leaving ten tanks for the regular work of sedimentation. The first rush of storm water, it should be added, is given the full treatment.

Each of the twelve tanks has a holding capacity of 212,000 U. S. gallons, and the average amount of sewage and storm water passed through them in 1902 was 4,017,000 Imp., or 4,820,000 U. S., gallons per day. Of the closed septic tank I learned only that it showed no advantages over open septic tanks.

The settling tanks are fed at the ends, each is operated continuously, independent of the others, and the discharge is in a thin sheet over end weirs. After two to three months' use each tank is put out of operation and floating arms are used to draw the settled sewage off in order to give access to the sludge, which is removed by gravity and finally by hand pushing to a channel for dosing with lime, when the sludge is pressed. Ejectors are used to force the sludge to the presses, or sometimes to two large storage tanks when the presses are working badly. Both the air compressors and the brushes used to clean the screens in the detritus chamber are driven by gas engines.

The sludge was at one time sold to farmers at a shilling, or about 25 cts., a load, but the demand became so small that it finally was given away, and apparently not all of it could be gotten rid of even on that basis. As has been stated, the greater part of the sludge, both pressed and thickly settled, is now discharged on land in a depression known as "Slacks Valley." The sludge contains a large percentage of chemically combined stearic acid, probably from domestic soapy water, and Mr. Valentine hopes to induce the health committee to install a plant for extracting grease from it. Already visible coagulated fat is skimmed from the tanks occasionally. The greater part of this fat is sent down the sewers on Tuesdays, which day the butchers devote to slaughtering animals with subsequent cleansing of tripe. A man comes 18 miles for the grease and pays 7½ shillings, or $1.82, per barrel for it.

The area of contact beds in use aggregates about nine acres, including one put in operation just before my visit. Additional beds were under construction at that time. The first four beds were put in operation in September and October, 1897, and had a combined area of 47,700 sq. ft. Other beds were added at intervals, until in November, 1898, there were eleven in use, with a total area of about 3.2 acres. These beds ranged from 1¾ to 2¾ ft. in depth, but were mostly 2¼ to 2¾ ft. deep. The next beds were completed in the latter part of 1900, and they and all later ones are 3 ft. deep. Until the close of 1901 all the filling for all the beds was "furnace ashes" from near-by mills, which was mostly soft, friable clinker. Since the date named hard, well burned clinkers from the borough refuse destructors have been used. Mr. Valentine's annual report for 1902 states that "there seems to be no essential difference as regards chemical efficiency between clinker and mill ashes as filtering material. The balance, if any, is in favor of mill ashes." The same report, however, speaks of the continuous loss of capacity of the beds and the breaking down of the "ashes." At the time of my visit Mr. Valentine was strongly in favor of refuse destructor clinker, on account of its greater stability.

The filtering material rests on the natural soil and the sides of the beds are formed of 3-in. planks supported by 3 x 4-in. verticals, braced inside. The report already quoted from speaks of serious leaks from some of the beds.

Several main carriers serve the various groups of beds. All of these are of wood, except one of concrete, built to replace a wood car-

rier wrecked during a heavy storm flow of sewage. The distributors or "shoots" on the beds are also of wood, dividing the beds into rectangular spaces. The "shoots" have been placed closer and closer together as new beds have been added.

The older beds had not only few distributors, but few underdrains also. These were of open and jointed tile. The very latest beds have more underdrains, made of perforated pipe and connected at their upper ends with ventilating pipes. These beds follow the Manchester model in that they have corner inlets, radial distributors (of half tile) and radial drains, returning to the same corner as the inlets.

The filtering material beneath the wood carriers, to some distance on each side, becomes of a "slimy, black and foully-smelling nature," but the distributors or "grips" formed of fine clinker above the main bed, like those at Manchester, would not do at the Oldham works, at any rate on the older beds, because there is no means, in time of flood, "of nicely regulating the flow upon the filters," so the channels would be destroyed or badly damaged. In addition, it is stated that the labor required to clean the wood carriers is less than that to clean the semi-circular clinker carriers. It is probable, however, that the system of grips may be tried upon the beds with the radial distributors.

The later beds have been arranged to receive sewage from the older ones, if desired. Some means of concentration will be necessary soon, as the land, which adjoins the Chadderton works, is nearly all used up and there is no more available in the vicinity.

The time required to fill the beds ranges from 25 to 90 minutes, according to the rate of the flow at the time and the capacities of the several beds. The period of contact ranges from 1½ to 6 hours, according to the character of the sludge and the age of the beds. The beds are emptied in two hours and rest from 3 to 6 hours between the fillings when filled twice per day. During most of the resting period "the exit valves are opened fully in order to assist aeration."

A new filter, when filled for the first time, will hold between 55 and 60% (water) of its completely empty capacity. That is to say, a bed measuring 100,000 cu. yds. will take between 55,000 and 60,000 cu. yds. of sewage when filled for the first time.

The 1902 experiments on capacity were simply to show that continued use during the years brings a decreasing capacity. The older filters have a capacity of about 20%—a great fall from the original 55%.

Chemical analyses of sewage tank effluent and filter bed effluent are made daily, besides which each filter is tested separately once a week.

The chemist has full charge of the operations of the tanks and beds, but the machinery of the plant is in charge of a manager who was originally a "fitter." The number and wages of the regular force, not including the chemist, who is on a separate pay roll, are as follows:

1 manager at £2½, or $12.15 per week.

1 fitter at 9d., or 18 cts. per hour.

1 engineer at 7d., or 14 cts. per hour.

16 laborers at 6d., or 12 cts. per hour.

1 lad to assist the chemist.

1 lad to assist the three filter men.

1 boy for general work (chiefly in connection with the sludge presses).

Of the 16 laborers three men, working one each in eight-hour shifts, attend to the application of sewage to the beds. Three additional laborers are employed in filling new beds with clinker and their wages are charged to the capital account.

My visit to these works was made in the rain, after several other rainy days. So far as I could judge under such conditions, the plant was being operated entirely without nuisance, as were practically all the plants, of every description, inspected by me during my trip abroad.

CHAPTER VIII.

Sedimentation Tanks, Septic Tanks and Double Contact Beds at Burnley.

After a somewhat varied experience with different methods of sewage treatment, Burnley has adopted sedimentation, septic tanks and double contact beds. During my visit to these works on April 15, 1904, I was impressed with the saneness shown in their recent development and operation. What has seemed to me like needlessly expensive construction at some other plants has been avoided here. The workings of the separate parts of the plant seem to be observed with more than usual care, and the obvious lessons to be learned from a careful study of the records thus obtained are intelligently applied to future design and operation. Of course, this is only as it should be,

and Burnley does not stand alone in these particulars, but my observations of sewage works in both Great Britain and America show that in both countries such conditions are comparatively rare.

Burnley is a cotton manufacturing town, with a population of about 97,000 and an area of 4,015 acres. In addition, some small outlying territory is tributary to one or the other of the two sewage works. The combined system of sewers is used, but in a considerable part of the borough the roof water from the fronts of the houses and from the front streets is discharged into the river by separate sewers. The rainfall from 1891 to 1900 ranged from 38.04 to 46.84 ins., averaging considerably more than 40 ins., while in 1903 it was 56.15 ins. Overflows to the river have been provided at numerous points on the combined sewers, but the volume going to the sewage works is several times the dry weather flow. Water closets are almost universal in Burnley, but about three-fourths of them are flushed by means of sink and other waste water which accumulates in tilting tanks. This results in a concentrated dry weather sewage.

The two sewage works, as they now stand, are similar in character, and as I visited the larger plant only I shall confine myself to its history and present status. Before proceeding further, however, I should state that I was most cordially received at Burnley and shown about the works by Mr. G. H. Pickles, Assoc. M. Inst. C. E., Borough Surveyor, and Mr. Raymond Ross, F. I. C., Borough Analyst. Connected with the early stages of the present works was Mr. F. W. Harris, who preceded Mr. Ross as borough analyst.

The history of sewage works at Burnley is worth noting briefly.* From 1878 until 1886 sewage disposal was effected by the Scott Sewage Purification Co. The sewage during this time was treated with lime in precipitating tanks, the effluent being discharged direct into the river. The sludge, after being dried on floors and burnt in kilns, was ground and used as cement. When the works were taken over by the municipal corporation in 1886, and from then till 1889, the above treatment was continued with the exception that the sludge was run into lagoons and allowed to dry. The borough added sludge presses in 1889. In 1892 it borrowed money to add four precipitation tanks and to buy 63 acres of land for land treatment of the tank effluent.

*This history, combined with an account of experiments preceding the change to the present scheme and a description of both the larger and smaller works as they were in 1901, is given in excellent form in a special report, chiefly the work of Messrs. Pickles and Ross, issued in April, 1901.

The first of the land was put in use in 1893. Early in 1896 some 40 acres, net, had been levelled, provided with embankments and underdrained. The drains were first laid 66 ft. apart, but soon this was decreased to 22 ft., on both the newly prepared and the older areas. The depth of the drains was from 4½ to 5 ft. The 40 acres, net, which appears to have been all the land available for treatment, was capable of dealing with only 500,000 Imp., or 600,000 U. S., gallons of chemically treated sewage a day, which was about a fourth of the dry weather flow reaching these works in 1896. After a most unsuccessful experiment with polarite filters in 1896, including also the substitution of ferrozone as a precipitating agent, it was decided in 1897 to make some tests of contact filters. Single contact with unscreened mill furnace ashes or cinders and with screened coke showed much better results from the cinders than from the coke, but neither being wholly satisfactory second contact beds, of fine screened furnace ashes or cinders, were installed. The results were so satisfactory that, on being pressed by the Local Government Board to provide a greater area for land treatment, it was decided to utilize some of the area already in use for double contact beds. It was also decided after a trial with two of the existing tanks to change all of the twelve tanks from precipitation to open septic treatment. One of the two tanks had been operated at a rate equal to one filling a day and the other at two fillings, but the differences in results were slight. During the three months of the test either tank gave effluents superior to those obtained with 13 grains per U. S. gallon of lime and 1.4 grains of copperas.

On reaching the works by gravity the sewage is passed through one or the other of two detritus and screening chambers, provided with ¾, ½ and ¼-in. screens, set tandem. The screens are cleaned by rakes on endless chains. Just enough lime, which averages about 0.18 grain per U. S. gallon, is added to the sewage to make it slightly alkaline. When sludge is being pressed the press water serves the same purpose.

The eight original tanks are 50 x 40 ft. x 7¾ ft. average depth, and the four newer ones are 75 x 40 x 6¾ ft. This gives a combined holding capacity of about 1,250,000 Imp., or 1,500,000 U. S., gallons, which in 1901 was a little more than half of the dry weather flow. The storm flow can be diverted from the septic tanks. Since 1902 two of the tanks have been used for detritus or plain sedimentation tanks, their effluent passing to the septic tanks. This gives a holding capacity

of about 195,000 Imp., or 235,000 U. S., gallons for sedimentation, and 1,075,000 Imp., or 1,290,000 U. S., gallons for septic action, with no allowance for tanks out of use for cleaning. One of the septic tanks has been covered, but I was told that it gives no better results than the open tanks. An overflow weir keeps the septic tanks supplied at the rate of one filling each twelve hours. Four of these tanks, at the time of my visit, were well covered with scum. The others had been cleaned more recently and showed little or no scum.

The deposit from the detritus tanks is removed about once in three weeks and from the septic tanks about once a year, the latter being a change from once in four months introduced when the detritus tanks were first used in 1902. After the sewage has been removed from above the sludge, lime to the extent of 3.34% of the latter, by weight, is added to the sludge and the mixture is allowed to settle over night. The resulting mixture of lime and sludge is then pumped to a sludge tank, thus giving a thorough mixing of the lime and sludge, after which further settlement and draining off of top water takes place. All the top water is sent back for another passage through the tanks. The pressed sludge is conveyed mechanically to a disintegrator and thence to the sludge storage rooms. The demand for this sludge manure, at about 20 cts. per long ton, was described in 1901 as "good and sufficient" and it is said that no difficulty has been experienced in disposing of the whole of it at this price.

Up to April, 1901, 14 acres of double contact beds, half for first and half for second contact, had been provided. Since then some changes have been made in the older beds and new beds have been added or put under construction, so when the latter are completed the total area will be about 20 acres. At present over 16 acres are actually in operation.

The filtering material is described as "nothing but well-burnt furnace clinker," which is apparently the same as the mill ashes previously mentioned. Various sizes of material have been used, all with satisfactory chemical results, but in the 1901 report it is stated that the best results and the least difficulty in working had been secured by material passing through a ½-in. and retained by a ¼-in. mesh, for the secondary beds, all above ½-in. material being used for the primary beds. Crushing has been abandoned as useless, regardless of the size of the clinkers reserved for the first contact beds.

From what I learned at the works I conclude that since 1901 the material first used has been found to contain altogether too much fine

matter. In fact, I was told as much, and was also informed that all material used hereafter would be both washed and screened. The material in one of the old beds was being so treated during my visit, and although it had been in use only some four years it seemed to be badly broken down. It was being wheeled up in barrows, dumped in a pit at the edge of the bed, where septic tank effluent was applied for wash water. From the pit bucket elevators lifted the material to a revolving screen. The fine ash from the screen was wasted; the 1/8 to 3/4-in. material was put aside for secondary beds; and all the large material was being put back in the primary bed.

I saw a new primary bed being filled and was surprised to see how easily lumps of clinker could be broken with the end of my umbrella and how much fine matter was being placed in the bed. The one weak point at Burnley seems to me to have been, if it is not still, the softness and fineness of the clinker or furnace ashes. Doubtless this will be largely remedied by the combined washing and screening recently adopted, but the waste of material, it would appear, will be great.

The simplest possible construction has been used for the beds, which it should be remembered are located on an area previously graded and drained for land treatment. Enough material has been taken from the bottom of the proposed beds to form the embankments and at the same time to give a slight fall to the outlet chambers.

The drains are laid on the ground surface forming the bottoms of the beds and have their upper ends carried above the level of the beds for aeration when the beds are resting and for observation chambers when the beds are working. The main drains have a fall of 1 in 200 and the branch drains of 1 in 600, and each outlet is provided with a full-way valve, all to favor rapid emptying and complete aeration. Most of the beds, including all the early ones, have a nearly uniform area of a little more than a half acre each, this size having been considered proper for the volume of sewage being treated, as it permitted the whole volume of sewage to be applied to one bed at a time and still not occupy more than 1½ hours for filling. The larger beds have areas of 1 to 1½ acres each, that size having been rendered convenient by the conformation of the surface of the land.

There is no automatic apparatus for filling and emptying the beds. Mr. Ross stated that a man must be employed to keep such apparatus in order, and that the latter might as well open the gates himself while on his rounds. This particular argument against automatic ap-

paratus was not advanced by any one else whom I met in Great Britain, but there may be some force in it. Obviously with many beds of considerable size in use and the whole sewage flow going onto a single bed, hand operation of the gates might be advantageous if not necessary.

It should be added that in times of heavy flow the sewage is applied to more than one bed at a time. The beds are filled to within 2 or 3 ins. of the surface, stand full about two hours, and stand empty until again required, which should not be less than three hours. Longer periods of rest are given when needed.

After two years of use the holding capacity of the primary beds was found to be reduced from 106 to 48 U. S. gallons per cu. yd., or 62%, and of the secondary beds only some 40%. The limited septic tank capacity is given as an explanation of the greater loss on the part of the primary beds. The working capacity of the old land treatment area is given as 10,000 Imp., or 12,000 U. S., gallons per acre per day, as compared with 192,000 Imp., or 230,000 U. S., gallons for the double contact beds at two fillings a day, and 257,500 Imp., or 309,000 U. S., gallons when filled three times daily with sewage diluted by storm water.

The average cost of the double contact beds, up to April, 1901, was 5 shillings, or $1.22, per sq. yd. of bed 3 ft. deep, but the excavation averaged only 6 ins. in depth. The main item was for the ashes or clinker, which cost 3½ shillings, or 85 cts., per cu. yd. The wood distributing troughs cost about 7½d., or 15 cts., per sq. yd. of bed, or more than double the main and lateral drains, aerating pipes and outlet valves. The unit costs of the later beds have been about the same as the figures just given.

The effluent from the secondary beds, as seen in a 12-in. test tube, appeared remarkably clear, in comparison with other effluents, but it had a slight cloudy look. The special report mentioned so often shows the reduction of organic matter effected by two or three pairs of contact beds. The monthly averages during the 15 months ending March, 1901, were from 30.7% decrease in albuminoid ammonia for the first contact and 83.3% for the second contact in March, 1900, to 81.8 and 91.6%, respectively, in February, 1900, all as compared with the septic tank effluent applied to the filters. The low result for the primary filter was abnormal, no other month showing less than 51% reduction.

CHAPTER IX.

The Rochdale Pail System and Sanitary Manure Works, Refuse Destructors and Sewage Works.

Rochdale has long been known in the United States for its pail system of nightsoil collection and its sanitary manure works. Combined with the latter is a refuse destructor, which burns such of the refuse as is not sifted to get combustible matter to evaporate the liquid from the nightsoil. Although practically all the nightsoil was excluded from the sewers some thirty years ago, land treatment of the sewage soon followed, then chemical precipitation and land combined. Not long ago one of the precipitation tanks was converted into a septic tank and the effluent from it applied to percolating beds by means of revolving sprinklers; and for two or three years past a portion of the chemically treated sewage has been applied to double contact beds.

Rochdale now has a population of about 84,000, of which 10,000 is in an annexed district mostly provided with waste-water closets, and having a separate sewage outfall and works. The principal sewage works serves a population of 65,000, all but some 6,000 of which have their nightsoil removed by the pail system. It should be noted here that nearly all the mills, factories and workshops employing both male and female labor are now on the water carriage system.

All the sewers are on the combined plan and there is no pumping. The borough is hilly, and there are storm overflows, all storm water in excess of six times the dry weather flow passing to the rivers and brooks untreated. The dry weather flow is now 2,000,000 Imp., or 2,400,000 U. S., gallons, and the maximum volume reaching the sewage works is 12,000,000 Imp., or 14,400,000 U. S., gallons. About one-fourth of the dry weather flow, or 600,000 U. S. gallons, goes to the smaller tanks at the principal works, and is still treated by chemical precipitation alone. Mr. S. S. Platt, M. Inst. C. E., is and since 1881 has been borough engineer of Rochdale. Mr. F. W. Brookman is manager and Mr. J. H. Heywood is assistant manager of the sanitary manure works, and Mr. Henry Ledson is manager of the principal sewage works. In the absence of Mr. Platt from Rochdale during my visit, on April 14, 1904, I was shown about by Mr. T. Williams, Assistant Engineer in charge of sewers.

The Sanitary Manure Works and the Refuse Destructor.

Although no American town of any size is likely to adopt the pail system of nightsoil collection instead of water carriage, I have thought it worth while to include a brief description of what has long been known as the Rochdale System. The pail system is also largely, but, I believe, less creditably, used in many other towns near Manchester, and in Manchester itself. I must confess, however, that after seeing the Rochdale manure works and at the same time learning the difficulties experienced at Rochdale in dealing with sewage practically free from excreta, I think more highly than ever of the full water closet system.

The Rochdale system of collecting and treating nightsoil was installed in 1869, and with changes in method of making the commercial fertilizer it has been in use ever since. The nightsoil is collected in covered pails, made by the borough, holding about 10 Imp., or 12 U. S., gallons each. The amount collected yearly is given as about 9,000 long tons, which for a population served of, say, 64,000, is about 313 lbs. per capita per year, or less than 1 lb. per day. The pails are brought to the manure works in covered wagons, and are emptied into a storage tank. They are then washed in a large trough, after which about a pint of chloride of lime, in a solution of 8 lbs. of bleaching powder (chloride of lime) to 40 Imp., or 48 U. S., gallons of water, is thrown into each pail. The collections are made from each house once in a week.

The nightsoil is evaporated in two stages: in revolving cylinders and on drying plates. The heat for drying is generated from screened borough refuse, in special furnaces placed end to end with the driers. The heat passes directly through the revolving cylinders, thus coming in contact with the moving surface of the nightsoil. When the latter has been reduced to the condition of thick mud it is removed to drying plates, beneath which the partly spent gases from the revolving cylinders are sent. These gases then pass through a spray washer to and through a condenser, and finally what remain are sent through a furnace. A Root's exhauster is used to increase the draft through the furnaces and the drying cylinders. A chimney 250 ft. high serves the whole establishment.

All refuse which is not passed through the shaking screen to produce fuel for the special boilers is burned in old refuse destructors of local design, fitted with Meldrum steam jets. The clinker from

these destructors is used for mortar making, and during the last three years for contact beds at the sewage works now completed.

Obviously a plant in which refuse is screened and burned and in which nightsoil pails are emptied and washed cannot be a pleasant place for visitors. The chief disagreeable features were the dust in the air and on the floors, and the very dirty clothes worn by the men who were washing the nightsoil pails.

The various classes of men engaged at the works receive the following wages per hour: Enginemen, 7¼d., or 14½ cts.; firemen, 6½ and 6d. or 13 and 12 cts.; riddle or screen men and general laborers, 4½d. or 9 cts.

The prices quoted in 1904 for small lots of fertilizer, but not less than two tons, delivered on the railway within 50 miles of Rochdale, were £5 14s., or $27.75, a long ton for ordinary, and £7 10s., or $36.45, for the ammoniated product, the former being made from the solid and the latter from the more liquid portion of the nightsoil.

THE SEWAGE WORKS.

The preparation for sewage treatment at Rochdale appears to have been started in 1880. In that year the borough purchased 80 acres of land for a sewage farm at a cost of £26,750, or about $130,000. Of this area only 49 acres were available for the treatment of sewage. The sewage was delivered to the farm through two outfalls, approximately one-fourth through one and three-fourths through the other. Since June, 1888, the sewage from the larger outfall has been treated on the land, and in October, 1890, chemical precipitation works were put in operation to deal with the sewage from the smaller outfall. It appears that the effluent from these small works has always been discharged into the River Roch without further treatment. The sewage coming to the larger outfall increased so in volume and also in proportion of trade refuse that in September, 1896, chemical precipitation works were established to aid the land, and about 1897 an addition of 11 acres, all available for intermittent filtration, was made to the sewage farm, making 60 acres then available for the reception of sewage, 5½ acres of which has since been taken for contact beds.*

*The sewage works up to 1897 were described by Mr. Platt in a paper read before the Incorporated Association of Municipal and County Engineers, from which some of the statements in this chapter are taken.

The 60 acres are divided into 24 level plots of from 1¼ to 3¾ acres each, with lateral underdrains 30 ft. c. to c., and at an average depth of 4½ ft. The drain outlets are about 1½ ft. above the ordinary river level, and are protected from floods by means of copper flaps. Embankments were necessary at some points to keep floods off the land.

Of the smaller precipitation works I will only say that the sludge from them is sent by means of an ejector worked by compressed air to the larger works for treatment, and that their effluent still goes directly into the River Roch, the sewage being easier to treat than at the main outfall, and the effluent generally being about the standard of the Mersey and Irwell Rivers Board, under whose jurisdiction Rochdale falls.

The sewage at the main works is described as very strong, sometimes containing 128 parts per 100,000 of solids and absorbing 13 to 20 parts of oxygen in four hours. It has been found necessary, especially during the summer months, to add sulphuric acid to the sewage on account of its excessive alkalinity.

The sewage first passes through bar screens, a grit chamber and fine screens. The grit is removed from the chamber by bucket elevator dredges and the fine screens are cleaned mechanically by rakes mounted on endless chains. After passing the fine screens the sewage receives from 8 to 10 grains per Imp. gallon, or from 6⅔ to 8⅓ grains per U. S. gallon, of alumino-ferric, which is incorporated with the sewage by three sets of revolving vertical stirrers or agitators. The sewage next goes in at the bottom and out at the top of one of two roughing tanks, each having a capacity of 105,000 Imp., or 126,000 U. S., gallons, from which grease is skimmed and barrelled. The grease is sold to a local man at about 10 shillings, or $2.35, per bbl. of 300 lbs. at the works.

The roughing tanks precede six chemical precipitation tanks, only five of which are now used for that purpose, each 40x160 ft., x 5 ft. average depth, and each of 200,000 Imp., or 240,000 U. S., gallons holding capacity. These tanks are operated on the continuous plan. When the sludge is to be removed the liquid above it is first pumped back to the mixing channel, after which the sludge flows to a sump and is pumped to an elevated brick tank having a capacity of 300 long tons. The sludge is pressed, broken up by being passed between a smooth and a toothed roll, and then dumped in a storage house. Farmers remove the sludge. In winter they

are paid sixpence, or about 12 cts., per load, which must be one long ton and may be as much more as they care to take. In summer the farmers contribute 2s. 8d., or about 62 cts., per long ton of sludge toward the cost of cartage and railway freight, which together cost 4½s., or $1.06.

The effluent from the precipitation tanks goes either to the land already mentioned or to some 5½ acres (taken therefrom) of double contact beds. The area of the primary beds is more than half of the total, but while the primary beds are about 2¾ ft. deep the secondary beds are a few inches deeper. Both sets of beds are composed of clinkers, partly from the Rochdale refuse destructor and partly from local mills, 1 in. and upward in size in the coarser beds and ¼ to 1 in. in the fine beds. The chemical effluent is admitted to a small pool in one corner of each bed, and flows over a curved concrete weir to the surface of the filtering material. The beds are relatively small, having an area of about one-half acre each. They are formed by earth embankments, and are provided with 4-in. drains, 9 ft. c. to c., connecting with larger drains, all laid in trenches cut in the ground. In other words, the preparation of the beds for the reception of the contact material was in striking contrast to the elaborate and costly floors and drainage systems provided in many other places, and also for the percolating beds at Rochdale. The 5½ acres of beds were estimated to cost £10,000, or $48,600, and actually cost some £8,000 to £9,000, or $5,000 to $10,000, less. They were put in operation early in 1903.

The effluent from the primary beds, in bulk, resembled a much-diluted black ink. I did not see the effluent from the secondary beds, but was given to understand that it was within the standard of the Mersey and Irwell Rivers Board. No odor was observed in any part of the works. My visit was made on April 14, 1904, which was a cool and rainy day.

Since September, 1899, one of the chemical precipitation tanks has been operated as an open septic tank of about 200,000 Imp., or 240,000 U. S., gallons holding capacity, receiving about 180,000 Imp., or 215,000 U. S., gallons of sewage a day. A pulsometer pump lifts the tank effluent from a small chamber and forces it through two Whittaker & Bryant* sprinklers on to percolating filter beds. The

*Since these beds were built the name has been changed to Candy-Whittaker sewage sprinklers, which are made by The Patent Automatic Sewage Distributors, 4 Westminster Palace Gardens, London, S. W.

beds rest on a smooth concrete floor having a gentle slope to an effluent collecting channel on one side. The drainage system is composed of "two courses of brick in rows, supporting 18-in. perforated half-pipes," above which is 9 ft. in depth of gas coke screened to exclude all material smaller than 1½ ins. in size. A checkerwork perforated brick shaft at the center of each bed serves both for ventilation and for a support to the revolving sprinklers. The latter consist of four 1¼ to 1-in. iron pipes, "perforated at various distances with holes of varying sizes, so as to ensure a uniform distribution of sewage over the surface of the filter."

To remove the suspended matter common to the effluent from all the percolating filters I have seen a settling tank of 10,000 Imp., or 12,000 U. S., gallons has been provided. This is cleaned of sediment twice a week. Mr. Platt states in a descriptive leaflet dated February, 1904, that "this experimental installation has been in operation since September, 1899, and has produced very satisfactory results." I was told that the beds were first operated at the rate of 600 U. S. gallons per sq. yd.; then at 480; and that their present rate was 450 Imp., or 540 U. S., gallons. The latter is equivalent to about 2,225,000 Imp., or 2,700,000 U. S., gallons an acre, and agrees with the statement as to total quantity, namely, 240,000 U. S. gallons a day, on the two filters, which have an area of 200 sq. yds. each.

CHAPTER X.

A Hydrolytic Tank Under Construction as a Preliminary to Old Triple Contact Beds at Hampton, Middlesex.

My last day in England was devoted to visiting a sewage works at which there was being carried out a modified form of septic tank, called a hydrolytic tank, based on suggestions found in the reports of the Massachusetts State Board of Health for 1900 and 1901. The new works are for the treatment of sewage preliminary to its application to triple contact beds, and it was in discussing the limitations of contact beds that the Massachusetts State Board of Health made the suggestions now being followed at Hampton.*

The first portion of the hydrolytic tank is designed to separate the two main operations of the ordinary septic tank, namely, sedi-

*Further information on this subject is given at the close of this article.

mentation and subsequent liquefaction, so that the two can be carried on quite independently. The chief advantages of this independent action are that the sedimentation chambers need be made only large enough for the optimum period of sedimentation, while deposited sludge, after being carried into the liquefying chamber, can emit its gases of decomposition without carrying large volumes of sediment up into the main current of effluent, to be deposited on contact or other beds. Another feature of the new tank is the provision made for drawing the sludge from the liquefying chamber while the whole tank is otherwise in normal operation.

The second portion of the hydrolytic tank consists of upward anaerobic beds which are designed to carry to a conclusion the anaerobic or liquefying process on such suspended organic matter as does escape from the hydrolytic tank, thus freeing the contact beds from sludge deposits and practically leaving them to deal with matters in solution only. In an original installation, it should be stated, contact beds would give place to so-called oxidizing beds, also based on suggestions found in the reports of the Massachusetts State Board of Health.

The ideas now being carried out at Hampton were evolved by Dr. W. Owen Travis*, assisted on the engineering side by Mr. Edwin Ault, of Shone & Ault.†

While awaiting the construction of this working installation Dr. Travis is devoting a large part of his time to experimental work on the treatment of sewage, for which purpose he has, at his own expense, installed a laboratory and chemist at the sewage works. I noticed in the laboratory two working glass models, nearing completion, one of the hydrolytic tank, the other of a novel form of oxidizing bed, both designed to treat 300 gallons of sewage a day, and I was informed that in the construction of this experimental installation, as well as in the conduct of the above mentioned experiments, valuable help was being given by Mr. Thomas Hughes, the capable manager of the sewage works.

Hampton is a suburb of London, with a population of about 7,500 and an area of 2,035 acres. Of the latter about half is occupied by Bushey Park, which is Crown land, and by the Southwark & Vauxhall, the West Middlesex and the Grand Junction

*Manor House, Hampton, Middlesex, England.

†47 Victoria St., Westminster, S. W., England.

Water Companies. The town has a river frontage of about 2⅓ miles, but it is occupied by the intakes of the water-works companies at the upper end, and by Hampton Court Palace below, while between lie public pleasure grounds and high class private residences. The summer level of the Thames above Molesey Lock is 21.5 ft. above ordnance datum, and below the lock is 15.5 ft. above datum. About one-tenth of the building area of the district is from 26 to 55 ft. above datum and nine-tenths is from 55 to 65 ft. above datum, or from 33.5 to 43.5 ft. above the summer level of the river. The treatment of the sewage was imperative before discharging it into the Thames at any point on such a water frontage. To locate sewage works on or near the river was out of the question. It was therefore decided to build the works on the side of the district furthest from the river and to lift the sewage to the works by means of eight Shone ejector stations, serving as many districts. The effluent outfall conduit is 3.15 miles long, and discharges into the Thames below Hampton Court Palace.

The slow progress of municipal work in England is illustrated by the following stages in the works: A Local Government Board hearing on the plans was held on December 12, 1894; the plans were approved on July 6, 1895; construction was begun on March 7, 1896, delay having been caused by awaiting the organization of a "works department" to carry out the bulk of the construction; the first sewer connection was made on December 8, 1898.

The sewers were on the separate plan, except that the rainfall from the back roofs is admitted. The subsoil water being within 3 ft. of the ground surface throughout a large part of the district, and within 18 ins. during the winter, subsoil drains were laid beneath every sanitary sewer. These were either 4 or 6 ins. in diameter, and were surrounded by broken stone which extended from the level of the top of the drains to from 12 to 15 ins. below the inverts. On the broken stone 6 to 7 ins. of concrete was laid to serve as a bed for the sewers. After the sewers had been laid and tested by hydraulic pressure the concrete was extended to a level a little above the center of the pipe. All the sewer pipe, it appears, was laid by a single man, and with great care, which partly accounts for the length of time required in construction, and for the low infiltration of 14,000 Imp. gallons, or less than 17,000 U. S. gallons, in 24 hours into 16⅓ miles of sewers laid in wet ground to depths of 5 to 16 ft. About 3⅓ miles of surface water drains or storm sewers were

laid, mostly in the same trenches as the sanitary sewers. Flush tanks were provided at the head of each line of gravity sewer. The total length of the cast iron sewage and air mains was 36,624 ft.

The ejector system was designed for 50 Imp. gallons per head per day from a population of 7,500, or a total of 450,000 U. S. gallons in 24 hours. The air compressing machinery, which is in duplicate, consists of two 15-HP. horizontal steam engines, with steam cylinders 12 ins. and air cylinders 15 ins. in diameter, both of 18-in. stroke. The maximum ejector lift is about 68 ft., or 78 ft., including friction. The effluent from the contact beds is used as boiler feed water.

The original plans for sewage works at Hampton provided for chemical precipitation and land treatment, and some 20 acres of land were acquired for the latter purpose. This was the scheme approved by the Local Government Board. During the delays over the construction of the works the contact beds put down by Mr. W. J. Dibdin at Sutton and London came to the attention of the Hampton authorities, and finally Mr. Dibdin was called in to aid in designing contact beds for Hampton. Shone & Ault were employed as consulting engineers for the whole sewerage system and sewage works. Mr. John Kemp, Assoc. M. Inst. C. E., was engineer and surveyor to the District Council. Mr. S. H. Chambers, the present engineer and surveyor, was at that time an assistant to Mr. Kemp. Mr. Dibdin prescribed the number, size, material and general arrangement of the beds, and the engineers made their plans accordingly.

The eight ejectors deliver sewage to a small open screening chamber, in which inclined iron bars are set, and from this chamber the sewage flows to the contact beds. Triple contact was adopted and the three sets of beds were formed in what may be described as three sets of concrete tanks, on three levels. There are five beds in each set. Each bed in the first set is 34x50 ft. in plan; in the second, 35½x54 ft.; in the third, 35½x58 ft. This gives a combined area of 28,380 sq. ft., or 0.65 acre. All the beds were 4 ft. deep. The first contact beds were filled with material rejected by a screen with a ½-in. mesh; the second with material that had passed a ½-in. mesh, but from which the fine dust had been removed; and the third contact beds were filled with "clinker sand."

The beds were designed to operate in eight-hour cycles, allowing an hour each for filling, standing full and emptying, and five

hours for resting. The valves or sluices are lifted by hand. The Local Government Board, on application for a further loan, objected to the departure from the original plans, but finally sanctioned the new loan on being promised that the effluent from the triple contact beds should be applied to land. After some eight months of discharging the effluent from the beds directly into the Thames, without a word of complaint from the Thames Conservancy Board, it was applied to the 20 acres of land originally acquired for land treatment. To raise the sewage to the land an air-lift pump was provided, which was considered advantageous on account of supplying air to the effluent. At the time of my visit I was told that the effluent was not being sent to the land.

It appears that the contact beds have proven themselves capable of effecting a high degree of purification, but that no little trouble has been occasioned by clogging. Originally the sewage was distributed over all the beds by means of half tiles, laid flush with the contact material. These have been retained on the second set of beds only. Each of the third set of beds now has three broad, shallow depressions which serve as distributors. From the inlet end of the upper beds the contact material has been removed to a depth of 9 ins., over a fourth of the area, thus forming deposit pools at the inlet ends of these beds and lessening somewhat the work of sludge removal from the surface. Notwithstanding this measure, there was quite a heavy deposit of sludge over the remainder of some of the first beds when I visited the works, on June 17, 1904. There was also a deposit on the secondary beds, and the surface of the third set of beds was not quite clean. I was told that the upper 6 ins. of the material in two of the lowest set of beds had been removed, washed and replaced, that all of the material in two of the secondary beds had also been washed, and that two of the primary beds had been sifted (not washed). The material forming a third bed in the second set was being washed while I was at the works. The washing apparatus was simple, but apparently effective. It consisted of a large box, with a bar screen near one end, and with compressed air pipes below. The dirty material was dumped from wheelbarrows into the box and stirred with a fork, the air being turned on meanwhile and the water carrying off the dirt. When clean the material was shovelled out. I was told that the material could be removed, washed and replaced by this means at a cost of 1½ shillings, or 37 cts., per cu. yd., which was less than the cost of new material in

place. I was interested in noting that the clinker in the bed was sufficiently impregnated with sludge to make it stand vertically where it was being removed, and that it was of an iron rust color.

The sludge removed from the pools and the beds is deposited close by them, and formed quite a large pile at the time of my visit.

When the contact beds were installed it was expected that there would be no sludge problem, and, as already stated, that the combined area of 0.65 acre would be sufficient for 60 U. S. gallons a day each from a population of 7,500, or a total of 450,000 U. S. gallons. The population, it is estimated, has already reached the maximum, but the present dry weather flow is said to be from 200,000 to 250,000 Imp. gallons a day, and may be assumed to average 250,000 Imp., or 270,000 U. S., gallons a day. Presumably many houses are not yet connected with the sewers. In wet weather the flow is two or three times the volume in dry weather, and several times in 1903 it amounted to 1,500,000 Imp., or 1,800,000 U. S., gallons, as shown by gagings. There are no storm overflows, so the full flow reaches the works.

On the total area of 0.65 acre of contact beds the average dry weather flow would be equivalent to 345,000 Imp., or 415,000 U. S., gallons per acre. It appears that the beds began to clog long before this rate was reached. It is probable that the actual rate per acre should be taken at a considerably higher figure, since the area now used as settling pools cannot pass much sewage, and since all the storm flow passes through the beds.

The new hydrolytic tank is designed to deal with a dry weather flow up to 300,000 Imp., or 360,000 U. S., gallons a day. Of this 87½% will pass through the two sedimentary chambers, with a stay of 5 hours, and 12½% through the liquefying chamber, with a 15 hours' stay. The upward anaerobic filters are designed for a three hours' passage of combined effluents.

It is expected that the hydrolytic tank will remove nearly all suspended matters from the sewage and will liquefy a large percentage of the suspended organic matter. The sludge space in the central liquefying chamber is estimated to be sufficient to hold the accumulations of sludge for two months, and this space may be completely filled without reducing the figured liquid capacity of the liquefying chamber.

The hydrolytic tank is composed almost entirely of concrete. It is to be covered, the roof having main supports composed of

heavy girders, encased in concrete. Some of the light partitions in the structure were designed to be of reinforced concrete, but it was found that large flagstones would be cheaper, and these are being used.

The sewage from the ejectors, having passed through a screening chamber, will be delivered into two small detritus tanks, with hopper-shaped bottoms, and from these it will overflow into the sedimentation chambers of the hydrolytic tank. Two longitudinal walls near the center of the tank divide the latter into three parallel chambers. The two outer and wider chambers have floors of flagstones sloping sharply upward from the outer to the inner walls. The floors are pierced, at their lowest level, by long, low ports, thus affording unobstructed passages between the sedimentation tanks and the central (liquefying) chamber. This chamber, it will be understood, is long and narrow from its top downward to the beginning of the sloping floors of the side or sedimentation chambers, beneath which it extends on either side. It has a curved bottom, provided at frequent intervals with vertical sludge ports controlled by valves. The liquefying chamber is subdivided by cross walls of concrete pierced at three levels by ports, the walls being designed to retard the passage of suspended matter through the liquefying chamber and at the same time to distribute the flow of the liquid through the whole depth of the tank.

At the outlet end of the tank each of the two sedimentary chambers, and also the liquefying chamber, is provided with an overflow weir. The length of the weir of the liquefying chamber is 12½% of the combined length of the other weirs, thus establishing the relative volumes flowing through the liquefying and the sedimentary chambers.

It will be evident from the foregoing description that the suspended solids of the sewage will be carried through the ports into the liquefying chamber by the force of gravity and by the volume of liquid entering therein, inasmuch as these ports constitute the only means of admitting sewage to the liquefying chamber. To reduce the deposits in the sedimentation chambers to the lowest possible minimum the bottoms of the latter between the ports are provided with cross-ridges to throw the sediment each way toward the ports.

Besides affording an opportunity for liquefaction and for sludge removal one of the main objects of the liquefying chamber is to pre-

vent the finely divided sludge deposited in the tank, when it is raised by gas bubbles, from being carried forward by the current and out of the tank.

It is expected that no such bubbles will find their way into the effluent from the two sedimentation chambers and that the several cross-walls already mentioned will intercept the greater part of the bubble-carried sedimentary matter in the liquefying chambers. It should be noted that although the hydrolytic tank is to be covered it is provided with regulated openings for ventilation purposes.

The effluent from the first part of the hydrolytic tanks passes over the weirs already mentioned into a channel leading to the upward anaerobic filters, or second part of the tank, which consist of a series of deep broken stone filters placed in compartments formed by cross-walls. The effluent will pass through each filter in the whole series, and provision is made for the removal of any sludge deposited in the filters, which can be flushed out through openings provided at the bottom.

The effluent from the anaerobic filters will be passed onto the triple contact beds, which will be able, it is expected, to treat the hydrolyzed and clarified sewage for some years to come.

The 20 acres of land acquired long ago for irrigation will be available for treating storm flow.

At the time of my visit the main walls enclosing the hydrolytic tank had been completed, the longitudinal walls forming the three chambers in the tank were part way up, and the flagstone floors forming the bottom of the sedimentation chambers were being placed. Construction was proceeding by the direct labor system, Mr. Sidney H. Chambers, the surveyor to the local authority, having charge of the work. Shone & Ault are consulting engineers and prepared the detailed plans, in accordance with the ideas of Dr. Travis.

Before closing this chapter it will be interesting to make some quotations from a pamphlet by Dr. Travis to show how he expresses his indebtedness to the Massachusetts State Board of Health for the principles upon which his experimental and practical work at Hampton is based. In the opening paragraph of his pamphlet Dr. Travis states:

> The conception of "The Hydrolytic Tank and Oxidizing Beds" is the result of a close study of the numerous experiments conducted at Lawrence under the ægis of the State Board of Health of Massachusetts, and published by that Board in a series of works which, in their entirety, constitute a classical record of the bacterial purification of sewage.

This being so, an acknowledgement of the source from whence the ideas were derived and a recital of the conclusions having special reference thereto are, as a matter of common honesty as well as of courtesy, equally desirable.

The last paragraph is notable, since not every one who has drawn inspiration from the Lawrence experiments has made proper acknowledgment of the fact, while some have made an acknowledgment in one phrase and belittled the experiments in the next phrase of the same sentence.

Dr. Travis next quotes certain conclusions of the Board drawn from its experiments on the septic tank and makes his own comments thereon as follows:

a. "The results obtained (in the septic tank) during 1899 (when owing to the low rainfall considerably stronger sewage had to be dealt with) have strongly indicated that the greater the amount of organic matter in the sewage entering a septic tank the greater will be the percentage reduction of organic matter by the tank treatment." This observation suggests the idea that "where exceedingly large volumes of sewage are to be purified, as in the case of the sewage of a large city, this sewage could be passed through ordinary settling tanks, so constructed that the sludge settling to the bottom of these tanks could be flushed into a septic tank and this sludge alone be treated by septic tank action, instead of attempting to treat the whole of a city's sewage. Following up this idea, a septic tank was put in operation during September, 1899, to receive the strong sludge from settled sewage." The results of this experiment, up to and including the year 1901, were "that the tank contained about 20 per cent of the organic matter of the sewage which had entered it during its period of operation," and "as the effluent contained about 22 per cent . . . about 58 per cent was liquefied or otherwise changed and given off as gas by the tank action during its period of operation." This was a rate of purification which exceeded that occurring in an ordinary septic tank during the same period, notwithstanding that in operating the tank the sewage was not moving through continuously, as the effluent passed from the tank only during the short time each day that concentrated sewage was being passed into it.

b. "During the first winter of its operation there was a constant accumulation of sediment within the tank," which was believed to be "due to the long period that the sewage remained in the tank at that time, and the consequent diminution of bacterial growth on account of the production of toxins." It is probable, however, that the absence of the pipe openings (i. e., absence of ventilation) upon the top of the tank, which was subsequently introduced, prevented the escape "of certain gases that, when held in solution in a closed tank, were inimical to the continuation of bacterial life."

c. "The matter in suspension in sewage is the chief factor in clogging the surfaces of . . . filters. . . . By the action of the septic tank a very large proportion of these matters in suspension is eliminated from the sewage when it flows from the tank. A certain proportion changes its form

and goes into solution in the sewage, while another portion is changed to the gaseous form and escapes; while undoubtedly at times, as has been repeatedly noticed at Lawrence, considerable very finely divided solid matter comes from the tank. This occurs at times when the movement of the gas in the tank disturbs the sludge, and, while only lasting for a few minutes at a time, causes considerable solid matter to flow out in suspension."

d. "It is evident, from our experiments, that the bacteria in the tank that do the larger proportion of the work live on the sides, bottom and top of the tank, where organic matter accumulates, and where they are found in enormous numbers compared with the numbers found in the liquid that is passing through the tank;" hence an experiment was inaugurated in 1899, "in which sewage was passed upward through a tank filled with broken stone, in order to afford a very extensive foothold and breeding place for the necessary classes of bacteria. Comparing the average analysis of the effluent of this anaerobic tank or filter with the average analysis of the effluent of the septic tank A, we see that the percentage reduction of organic matter was greater in the former, and that an effluent was produced containing a smaller amount of matter in suspension and hence more easily filtered at high rates." In 1901, when the applied sewage passed through the filter in about six hours, or nearly four times as fast as similar sewage passed through the septic tank, it was found that "the principal obstacle in operating an anaerobic filter such as this, compared with the operation of a septic tank, is the greater difficulty in removing accumulated sludge, if we assume, as seems reasonable, that in both cases sludge will (when treating most sewages, eventually) accumulate to such an extent that its removal will be imperative."

From the foregoing quotations, and the description of the hydrolytic tank already given, it is apparent how closely the suggestions made in the Massachusetts reports have been followed in working out the various details of the hydrolytic tank.

Dr. Travis is not a believer in contact filters. He is working experimentally on what he terms oxidising filters for a substitute and in his pamphlet he quotes at length from the Massachusetts reports to show the principles which he believes should govern the final stage in the treatment of sewage.

His own conclusions, based on the quotations, are in favor of "intermittent continuous filtration," with provision for exhausting gases from and supplying air to the filters and also for conserving the heat of the sewage in cool weather and for heating the air supplied to the filter in cold weather. Dr. Travis advocates a filter that will give high nitrification because the Massachusetts experiments indicate that by such means the highest attainable reduction in sewage bacteria can be secured, from which he argues that the sewage may thus be freed from pathogenic germs.

CHAPTER XI.

Chemical Precipitation, Sludge Removal by Siphonage, Contact Beds and Land Treatment at Chadderton.

Sewage works are so numerous in parts of England that on several occasions I passed close by one in going to another. In this way I chanced upon the Chadderton works. In fact, I was sent to them by mistake one rainy afternoon on inquiring my way to the Oldham works. The manager, Mr. Walter Foster,* suggested that since I was on the ground I might as well see his works. I was well repaid for stopping, as the Chadderton works are quite different in several respects from any others I have visited. I was also interested in finding works which, although built in 1898, employ chemical precipitation as a preliminary to single contact beds. The small area used for land treatment, as I understand it, receives effluent direct from the precipitation tanks.

Chadderton is a Lancashire urban district of about 25,000 population, not far from Manchester, and with its disposal area adjoining that of the borough of Oldham. Mr. A. W. Cox is district surveyor. Combined sewers and sewage disposal works were completed in 1898, with Mr. James Diggle, of Heywood, Lancashire, as engineer. The dry weather flow is about 800,000 Imp., or 960,000 U. S., gallons. Storm water and sewage to about three times this amount is treated at the works, the surplus being sent untreated to a brook which discharges into the River Roch. The effluent also goes into the brook. Only a small part of the sewage is pumped. Alumino-ferric is used as a precipitant, but the sewage is first screened by means of bars, cleaned by revolving rakes driven by a water wheel operated by the incoming sewage. There are six precipitation tanks, each with a capacity of 125,000 Imp., or 150,000 U. S., gallons, operated separately on the continuous flow plan.

The sludge is siphoned from the tanks, without drawing off the sewage above, by means of a horizontal pipe, placed a little above the bottom of the tank, perforated on the bottom, and connected with vertical pipes. A squeegee is hinged to and below this pipe and the combination is mounted on either end on cog wheels running on a cog rail at either side of the bottom of each tank. The squeegee may

*Middleton Junction, England.

be raised or lowered from above by means of a lever, and the whole apparatus is driven forward by means of a hand winch on a movable platform at the level of the division walls of the tanks. After being siphoned out as described the sludge is pressed and given to farmers. I saw a large pile of it awaiting removal.

The chemically treated sewage flows from the tanks over a weir into a channel, and thence to and through a feed channel placed at right angles to the contact beds. There are twelve beds, each about 15 x 60 ft. in plan, giving a combined area of 10,800 sq. ft., or about ¼ acre. The beds are about 38 ins. in depth, composed of 1 part of clinkers and 3 parts of coke, mixed, except that 9 of the 12 beds have their upper 6 ins. composed of sand. From the bottom upwards the material is arranged as follows: 9 ins. of a size of 2½ ins.; 6 ins. of 1½; 5 ins. of ¾; and 18 ins. of ½ to ¼-in. for three of the beds and 12 ins. for nine of them, above which, in the nine beds, comes 6 ins. of sand. The larger coke was brought from the Oldham municipal gas works and cost 6s. 7½d., or about $1.60 per long ton, delivered. For the smaller sizes coke breeze screenings were used, at a cost of 3s. 1½d., or about 75 cts. per long ton, delivered. The clinker or cinders were got for the cost of carting, which was 1s., or 24.3 cts. per load, but not nearly enough clinker to fill the beds was available.

The floors of the beds are of concrete and have a fall of 3 ins. in their length. The main drains are 12 x 6 ins. in section, of dry brick, and are laid down the center of each bed. Branch drains of half pipe, raised on feet and laid with open joints, extend from the main drains to the sides of the beds, where they connect with vertical pipe brought to the level of the division walls for ventilation. There is a 9-in. branch drain at each end and at the middle of each bed and two 4-in. drains halfway between the others.

The precipitated sewage is admitted to each bed through an iron channel extending the whole length of the bed, from which it overflows to the bed in a thin sheet. The rate of application is given as 400 Imp., or 480 U. S., gallons per sq. yd., which would provide for only some two-thirds of the dry weather flow. The rate given is 2,323,000 U. S. gallons per acre.

The tops of the beds covered with sand are cleansed weekly by means of an upward flow and once in three months the sand is removed and washed. The beds having clinker and coke surfaces are raked over during resting periods. In only one of the twelve beds has the upper 6 ins. been renewed since the beds were put in operation in

1898; and the renewal in that case was not until after four years of use.

The contact cycle was given to me as one hour each for filling, standing full, emptying and standing empty, which is the shortest cycle yet brought to my attention, but it was said that the beds rest at night, the sewage meanwhile going onto the seven acres of land. The River Roch, which finally receives the effluent, is under the jurisdiction of the Mersey & Irwell Rivers Board.

I was informed that alumino-ferric, used as a precipitant, costs 9 shillings, or about $2.20, per long ton, and that 5 cwt., or 560 lbs., is used per 1,000,000 Imp. gallons of sewage. This is at the rate of 3.92 grains per Imp., or 2.27 per U. S., gallon.

Besides the manager the force at the sewage works includes five men, two of whom are paid 4½ shillings, or $1.09, and the three others are paid 4s. 3½d., or $1.04 a day, for a working day of nine hours.

CHAPTER XII.

Grit Chambers, Contact Beds Followed by Intermittent Filters, with Land for Storm Flow at Aldershot.

Aldershot, like Salisbury, has a refuse destructor, sewage pumping station and sewage disposal works combined and under a single manager, and like Salisbury the heat from the destructor is utilized to pump the sewage. Some of the clinker from the destructor has been used for making contact beds at the works. I went to these works on March 30, after visiting the Aldershot Camp sewage farm.

Mr. John Edwards is manager of the Aldershot town works, and I judge from what I learned elsewhere that he has been largely responsible for recent changes in the sewage works. The works were put in operation in or about 1877 as a chemical precipitation plant. Twelve years later the effluent was applied to land. In 1897 so-called bacterial treatment was begun, and now all the precipitation tanks and a part of the farm lands have been converted into contact and filter beds. When the last change was inaugurated the sewage farm embraced 33 acres, practically all of which was receiving the effluent from the chemical precipitation works. Except for the portion laid out in beds the farm is now used to receive the storm flow only.

Aldershot falls in that class of municipalities known in England as an Urban District. It has a population of about 17,000. Mr. Nel-

son F. Dennis is engineer and surveyor to the council. Mr. Edwards has been manager of the sewage works for some 18 years.

The dry weather flow of sewage averages about 500,000 Imp., or 600,000 U. S., gallons. Not all the storm flow is pumped, most of it apparently going to the storm water filters, and thence onto the old sewage farm.

The sewage is pumped from a rather large receiving reservoir, holding 1,000,000 Imp., or 1,200,000 U. S. gallons, into two small grit or detritus chambers about 10 x 25 ft. in plan, and flows thence to the coarse beds, which are operated as contact beds. It next flows to the fine beds, which are operated as intermittent filters. There are a number of beds of each class, about equally divided in area and aggregating about 1½ acres. The coarse beds are 4½ and the fine beds only 1½ ft. in depth.

The coarse beds are formed of very large rough clinker, say 6 to 8-in. cubes, for the first 2 ft. from the bottom, above which is 15 ins. of ash or cinders from locomotives and then 15 ins. of small clinker from perhaps ½-in. down to dust in size. The fine beds have a layer of 1 to 3-in. cubes to a depth of 6 or 7 ins. at the bottom, above which comes fine material like the top layer of the coarse beds. The object of the fine material, in each case, is to keep the beds from clogging below the surface. Clinker from the destructor has been used to fill the beds recently. The sewage is admitted at one side of the coarse beds and at both sides of the fine beds, in both cases at the top. The contact beds are filled in about 2 hours; stand full 2 to 3 hours; require about 1 hour to empty; and stand empty for varying periods, depending on the rate of flow. Generally there are three cycles in 24 hours, but there is not always enough sewage for that. The discharge from the coarse bed flows to and through the fine bed without hindrance.

There is no automatic gear. The coarse beds are not underdrained. There is a brick drain in the center of each fine bed.

The coarse beds rapidly become covered with sludge and generally one bed is cleaned each day, which makes a forking for each bed about once in two weeks. Shovels are used to skim off the deposit, after which the bed is forked to a depth of 8 or 9 ins. by means of forks having 12-in. tines. I saw a man forking one of these beds. He dug deep and thoroughly. Only a little sludge accumulates on the fine beds. Save for a few barrow loads to level the surfaces the material in none of the beds has been renewed.

The beds are operated by a force of three laborers, who receive 24 shillings, or $5.83, a week, with no extra pay for night or Sunday work when required. The men change about for the Sunday work, so the man who has to work on Sunday leaves early on Saturday.

I visited the works on a cool day, after a rainy spell and a very wet winter. No odor was observed. The sewage farm, or present storm water area, showed signs of ponding. The effluent from the secondary bed appeared to be clear.

PART II.

Works Employing Percolating Filters for Final Treatment.

CHAPTER XIII.

The Change at Birmingham from Chemical Precipitation and Sewage Farming to an Elaborate System of So-called Bacterial Treatment.

The boldest of the large sewage works now being constructed in England is that of the Birmingham, Tame and Rea Drainage District, serving Birmingham and a number of outlying towns. When these works are completed one may see combined in a single plant automatic screening apparatus, settling tanks, open septic tanks, a five-mile effluent conduit, Dortmund settling tanks and percolating filters, each a separate stage in the treatment employed. In addition, the sludge will continue to be dug into the land, as it now is, and the greater part of the immense sewage farm will be available for the reception of storm water and for grazing purposes. As will become more apparent as this description proceeds, the final works will involve a heavy capital outlay, so heavy that it will be well worth while to watch the works in order to see whether the reduction in operating expenses will offset the increase in capital charges due to such a combination of processes and such permanent construction as has been adopted for some of them.

One of the most notable features of the new works, and one which might well be followed elsewhere in England, is the use of a hard, permanent material for the percolating beds, instead of the soft, easily broken down stuff so generally used in the various classes of so-called bacterial beds elsewhere.

These works are all the more interesting because they include by far the largest sewage farm in Great Britain or its dependencies, which up to 1900 had for many years been receiving the effluent from outfall works where chemical treatment was a leading feature. Very soon after assuming charge of the works as engineer to the Drainage Board, Mr. John D. Watson shut down the chemical plant, thereafter using some of the old tanks for sedimentation as a pre-

liminary to septic action in the other tanks. Since then a sufficient number of new tanks has been added to provide all the septic tank capacity needed for the present, and the other parts of the proposed works have been put under construction. Meanwhile the sewage farm has been receiving septic instead of chemical effluent.

Besides shutting off lime or other chemical treatment, Mr. Watson simplified the operations of the sewage farm by radically changing the method of sludge disposal and minimizing cattle breeding, preferring to sell farm produce rather than milk and stock. It would appear, however, that the strain upon the land following the application of septic sewage, with its greater content of suspended matter, was one cause for reducing the number of live stock. As the so-called bacterial works are installed the land will be more and more relieved, until it is less burdened than formerly, but if more stock is then added it will be stock for fattening rather than for milking.

The population of the drainage district in 1901 was about 793,000, on an area of 58,893 acres, or more than 90 sq. miles. This population is in excess of that contributing to any other sewage works, save London, in all England; but, the water consumption of Manchester being higher than that of Birmingham and vicinity, the dry weather flow at Manchester is larger than that at Birmingham. Birmingham alone had a population of 522,000 in 1901, on an area of 12,705 acres. The water supply of nearly the whole district comes from works owned by the city, and in the past has been wholly by pumping. The average daily per capita consumption is about 25 Imp., or 30 U. S., gallons, and the average daily dry weather flow of sewage is about 30 Imp., or 36 U. S., gallons. The difference between the water consumption and the sewage flow is accounted for as subsoil water and as trades and other wastes from independent sources of supply. When the new gravity supply of soft water from Wales comes into use, as it will soon, it is expected that there will be a material increase in the dry weather flow. The total dry weather sewage flow is about 25,000,000 Imp., or 30,000,000 U. S., gallons a day, and the storm flow is as high as six to nine times that amount. About a tenth of the dry weather flow reaches the sewage farm below the septic tanks and a new electrically driven screening plant and silt tanks are now being constructed to deal with this flow of sewage.

About twice the dry weather flow will be given full treatment, and all in excess of the latter amount and up to six times the dry weather flow will be applied to storm water filters, after first having been passed through the sedimentation tanks. Above six times the dry weather flow the sewage will go to the River Tame without treatment. The effluent also goes to the Tame. That river is a small stream with a minimum flow not more than the dry weather flow of sewage. Only a small part of the whole district has separate sewers. There are still many pail closets in use, but their number is being rapidly reduced year by year.

Early in 1903 there were in the district tributary to the sewers 354 works discharging trades wastes consisting mostly of spent and diluted hydrochloric, sulphuric and nitric acid, amounting to nearly 5,000 carboys per week. About 100 tons of lime per week are also discharged into the sewers, besides wastes from breweries, gas works and a variety of other establishments.

The sewerage system of Birmingham was begun in 1852, with a discharge of untreated sewage into the rivers Tame and Rea at Saltley, the location of the later precipitation works. Only three years later the borough strongly advised the treatment of sewage by irrigation, and after another three years, or in 1858, the borough was enjoined, as a result of a private suit, from discharging sewage into the River Tame. In 1859 two large tanks, with capacities of about 1,150,000 and 1,250,000 U. S. gallons, respectively, were constructed and upward and downward filtration tried. This process was abandoned, but the tanks were subsequently used for chemical precipitation and form a part of the existing tank system. Two sets of smaller tanks were built in 1859-60. After agitation in 1866 and 1871 in favor of land treatment a bill authorizing the acquisition of land for that purpose was introduced in Parliament, but owing to opposition it failed.*

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*These and many other particulars have been taken from "The Purification of Sewage, with Special References to the Works of the Birmingham, Tame and Rea District Drainage Board," being a lecture delivered by request of the Council of the University at the University of Birmingham on Feb. 19, 1903, by Mr. Watson, and since published in handsome form for private circulation only. The lecture, which is a most valuable contribution to the literature of sewage disposal, included a historical sketch of the old works and an illustrated description of the new ones, as then built and proposed. The statements regarding recent developments have, so far as possible, been brought down to the time of my visit to the works in April, 1904.

To satisfy the Court of Chancery lime treatment was adopted soon after, two more tanks constructed, 161 acres of land bought and 106 acres leased for irrigation. The drainage board was formed in 1877. By 1880 the sewage farm had been increased to 272 acres, and in 1881 it was enlarged by purchase to 1,139 acres. In 1897, 900 acres more were bought, and later additions have brought the total area up to 2,830 acres.

The accompanying table shows the character of the crude sewage and various effluents at the works during 1903.

Table of Analyses Showing Average Composition of Sewages and Effluents from the Purification Works of the Birmingham, Tame and Rea District Drainage Board During the Year 1903.
(Results expressed in parts per 100,000.)

Dis. solids.	Susp'd solids.	Free ammonia.	Album'd ammonia.	Chlorine.	Nitrates and nitrites as nitrogen.	Oxygen abs'd.	Nature of sample.
ANALYSES OF CRUDE SEWAGE.							
142.9	55.3	3.116	.960	12.3	.732	20.843	Saltley Sewage.
127.3	60.6	2.916	1.309	21.5	.816	23.998	Rea "
124.9	62.3	2.730	1.166	20.5	.908	25.366	Hockley "
107.8	120.0	3.061	1.479	16.1	.793	23.387	Aston "
123.5	73.6	2.910	1.283	19.4	.831	24.024	Computed Average.
ANALYSES OF TANK EFFLUENTS.							
104.2	8.5	2.591	.501	17.7	.189	18.464	Roughing Tank No. 5.
112.3	14.9	3.115	.753	17.9	.688	16.996	" "
104.0	13.4	3.712	.646	17.5	.433	13.799	Septic Tank.
ANALYSES OF FARM EFFLUENTS.							
100.1	1.1	1.281	.102	14.2	.614	1.468	Castle Bromwich Effluent.
63.4	1.0	.715	.071	8.4	.568	1.268	Plants Brook "
90.4	1.5	1.621	.103	13.7	.660	1.688	Minworth "
96.9	2.5	1.993	.107	14.9	.515	1.764	Water Orton "
89.1	2.0	2.077	.128	13.8	.470	2.220	Curdworth "
ANALYSES OF SPECIAL LAND EFFLUENTS.							
111.6	trace	.290	.076	12.5	1.757	1.612	Field No. 27 (Gravel & Sand)
93.3	"	2.426	.106	16.0	.304	1.719	" No. 29 (Ferrugium Clay)
90.2	"	3.029	.131	16.3	.337	2.888	Peat Land.
150.3	1.7	1.969	.150	16.1	.878	2.314	Old Sludged Land.

Average purification in land effluent on crude sewage:—

On albuminoid ammonia basis........................ 92.0%

On oxygen absorbed basis.......................... 93.0%

From about 1872 until early in 1900 all the sewage was treated with lime. In 1898 the lime treatment cost £4,332 or about $21,000, of which £3,532, or some $17,000, was for lime, which was used at the rate of about 10 grains per U. S. gallon.*

The lime bill was cut off early in 1900 by changing from chemical to septic treatment, and by means of hard work and careful management the land has been receiving practically all the septic effluent ever since. Meanwhile new tanks have been added, storm water filters built and experiments with so-called bacterial filters have been made. For two years or so two 1/4-acre percolating filters have been receiving septic effluent and some small contact bed filters were used experimentally for a considerable time before that. At the time of my visit, in April, 1904, several acres of additional percolating filters and Dortmund tanks were under construction.

As the works are now operated the outfall sewer discharges into five settling tanks, each of more than 1,000,000 Imp., or 1,200,000 U. S., gallons capacity, and each divided into three compartments. The sewage flows through these tanks at the average mean rate of 1.2 ft. per min., which gives 4.36 hours sedimentation. A large amount of road detritus, accompanied by lighter entangled material, is deposited in the first compartment of these tanks and is removed about once a week by a Priestman digger or dredge, operated from a travelling crane. This material is about 50% water, and is dumped into wagons, by which it is taken to a tip for burial in the earth. To gain access to this deposit, and also to the sludge in the other compartments, the partly settled sewage is removed by pumping, being delivered to high-level land. The sludge in the second compartment, which is about 90% water, is removed once a week. Part of it goes by gravity and the remainder is pushed by hand to pipes connected with a sludge pump, which delivers the sludge into a tank or else directly to the sludge main. From this tank the sludge goes by gravity to a Shone ejector, near by, which is used to force the sewage through a main 3 1/2 miles in length. Spaced 600 ft. apart along this main are chambers containing branch pipes and a valve on both the main and the branch. A 9-ft. length of armored rubber hose is used to connect the branch pipes with portable steel pipes, having flanged

*Up to 1871, seven different processes of chemical treatment had been tried at Birmingham, and one, at least, was supplemented by filtration through coke. The A. B. C., or alum, blood and charcoal, process was among these.

and bolted joints. The sludge is delivered through the portable pipes into head trenches connecting with a series of parallel trenches 3 ft. wide, cut 18 ins. below the ground surface, but with the dirt thrown upon either side so as to allow the trenches to be filled with sludge to a depth of 24 to 30 ins. As soon as convenient after being filled the sludge is covered with earth. In summer the sludge is sometimes covered within 24 hours from the time of taking it from the tank, but usually a week elapses before covering. In the growing season a crop may be sown on the land ten days after the trenches are filled, but as a rule, it appears, rye is sown on the sludge area in the autumn. After the rye is harvested the following summer the land is turned over deeply with a steam plow and the mixture of sludge and earth is left to the action of the winter frosts and rains. In the second spring sludge can be again applied. In fact "on more than one occasion the land has been trenched and sludged twice within two years."

A total of about 100 acres of land is used for sludge disposal, not including the sludge from the septic tanks.

Until the Autumn of 1902 the sludge was pushed to the land disposal area by hand along wood troughs resting on trestles. Eventually all the sludge, to prevent clogging the sludge pumps with rags and other matter, will pass through small chambers, in which will operate rakes on endless chains. These rakes will be cleaned, as they turn at the top, by means of fixed rakes. The apparatus will be driven by electric motors, covered by suitable houses, one for each tank. Thus far only one tank has been equipped as described.

Septic action is begun in the third compartment of the five settling tanks* and continued in 20 open septic tanks. The septic tanks have an average depth of 6 ft. and a total holding capacity of 7,260,000 Imp., or 8,700,000 U. S., gallons.

All the storm flow passes through the settling tanks and the septic tanks, and ultimately six times the dry weather flow will be treated on the percolating beds. At present there are four storm

*Formerly, it appears, the third, like the second, compartment, was cleaned once a week. Measured in the direction of flow, the first compartment is relatively short, the second longer and the third longest of all. As originally operated the sewage passed over stop planks into the second and beneath stop planks into the third compartment. The last two compartments were then cleaned together, as described for No. 2. At the time of my visit, in April, 1904, No. 3 was being operated separately as a preliminary to septic action.

water filters, with an area of one acre each. They are composed of coke 3 ft. in depth and about 1 to 1½ ins. in size. Generally these filters are idle between storm flows.

The septic tanks were used for about 3½ years without having any sludge removed. After pumping off the liquid above the sludge the latter was pumped to a large bed in January, 1904, where it still remained in April, 1904. As soon as dry weather arrived Mr. Watson proposed to plow it in and sow a crop on the land.

About 60% of the septic tank sludge (dried sludge) was inorganic matter and had no more smell than ordinary garden mould. The actual analysis of sludge from the bottom of tank No. 20 showed 55.33% of inorganic matter and 44.67% of organic matter. Of the latter, 2.47% of the total dry sludge was in the form of organic nitrogen. The inorganic matter was divided approximately as follows: Sand, etc., 20%; oxide of copper, 1.71; oxides of iron and aluminum, 20; oxides of zinc, manganese and nickel, 5; lime and magnesia, 7; oxide of phosphorus and alkalies, 2; total, 55.71.

Mr. Watson stated that the septic tanks should have been cleaned in warmer weather, when the septic action is greater, and that he does not mean to let them remain uncleaned so long as three years again.

Although practically all the septic tank effluent is still treated on land, it will be best to describe next the further stages in the so-called bacterial processes.

The effluent from the septic tank will flow five miles in a closed conduit, which Mr. Watson describes as a virtual continuation of the septic tanks. At the end of this conduit it will be received in Dortmund tanks, in order to remove the humus, or finely divided suspended matter, common to septic effluent. The conduit has a fall of 2 ft. per mile and the river 9 to 10 ft. per mile, giving an available head of about 40 ft. between the Dortmund tanks and the effluent channel communicating with the river, thus giving free scope to the design of the works without the necessity of pumping. As a result the Dortmund tanks could be made deep and the sludge still be sent to the land by means of the head of the liquid in the tanks, and the effluent from these tanks could also be distributed by gravity at will.

Thus far the plans made provide for only five Dortmund tanks, all of which have been put under construction. Mr. Watson proposes to build enough Dortmund tanks to receive all the septic effluent.

The tanks will be 44 ft. in diameter and 32 ft. deep from the weir level to the bottom of the sump or conical portion. The holding capacity of each tank is 161,000 Imp., or 194,000 U. S., gallons, thus giving a combined holding capacity of 646,000 Imp., or 775,000 U. S., gallons. Allowing four hours for sedimentation, or six fillings per day, each tank would treat about 1,000,000 Imp., or 1,200,000 U. S., gallons a day, and the five would receive and pass about 6,000,000 U. S. gallons a day. The maximum velocity through the cylindrical portion of the tanks would be at the rate of 4.4 ft. per hour, the period of sedimentation 2.6 hours and the corresponding hourly volume 75,000 U. S. gallons an hour.

The sewage will be admitted to the tanks about 18 ft. below the water level, and will be drawn off by means of central trough weirs at the water level on the line of the diameter of the tank. The sludge or humus will be removed from below, without disturbing the flow of sewage through the tanks, discharged by gravity on drying beds some distance from the tanks and eventually plowed in. The conical-shaped bottoms of the tank are built of concrete and the cylindrical walls are of brick.

At the time of my visit two circular percolating beds, each 120 ft. in diameter and with 7 ft. of effective depth, were in operation, and two of similar dimensions were under construction,* making a combined area of one acre. These beds are supplied by means of revolving sprinklers of different types, and the effluent from them will have no further treatment. There were also under construction in April, 1904, three primary and one secondary percolating beds, each with an area of one acre, provided with fixed instead of revolving sprinklers.

The percolating beds with revolving sprinklers receive effluent from the septic tanks, but when the Dortmund tanks are completed the septic effluent will be passed through them, and then applied to the single percolating filters, with revolving sprinklers, and also (and independently) to the primary and secondary percolating beds with fixed sprinklers.

The first two circular beds, it appears, were originally erected experimentally on storm water beds at Saltley, near the septic tanks. They were composed of 4½ to 5 ft. of coke, placed on a false floor resting on bricks arranged to form parallel channels. One was sup-

*These were in operation in June, 1904.

plied with a Scott-Moncrieff and the other with an Adams revolving sprinkler. On the determination to adopt the system permanently they were removed to the site where I saw them (Curdworth). It seems that both of these beds on the permanent site have been refilled to a depth of 7 ft. with other material. I shall describe the beds as I saw them, and in the order of arrangement, instead of age.

Bed No. 1, already in operation, is composed of iron slag, about as large as a man's head for the first foot from the bottom, then the size of a man's fist, and diminishing to ¾-in., and smaller at the top. There are no underdrains, except as afforded by the large pieces of slag at the bottom of the bed, and the side walls are also of large blocks of slag, laid dry. The slag has swelled and bulged outward, making it necessary to put iron bands around the outer wall. A Mather & Platt revolving sprinkler is used on this bed. It consists of two perforated radial troughs, revolving on ball bearings, and provided with a central feed pipe. By means of automatic apparatus the sprinkler works about once in ten minutes.

The material in bed No. 2, which I found under construction, is of gravel, large at the bottom and graded in size, so as to finish with, say, 1½ to ½-in. material. For the first 1½ to 2 ft. from the bottom the side walls are laid in mortar, and above that level they are built of dry stone, well bonded. The gravel for this bed was being washed by sewage (septic effluent), both to free it of sand and dirt and to inoculate it, Mr. Watson states, with nitrifying organisms. The underdrains extend through the outer walls, to serve as air inlets, and slope from the walls to a pair of main drains, which discharge beneath the bed. The drainage system will be described in more detail hereafter. The revolving sprinkler arms will be driven on the Barker's Mill principle, which, it has been found, will work under a head of 18 ins.

Bed No. 3, which I saw in operation, is composed of broken Staffordshire brick, graded from the bottom upward in sizes of 2½ or 3 ins. to ½-in. This bed has a Scott-Moncrieff sprinkler, which can best be described by quoting from Mr. Watson's lecture, as follows:

It consists of two girders, 60 ft. long, supporting an open trough, which is supplied with sewage from a central pipe, round which the trough revolves as on a pivot. The water is admitted through adjustable orifices in the main trough to a side trough, which is divided in eight divisions of equal length. The sewage flows in an equally thin sheet over the adjustable side of each

division, and streams very equally on to the bed. It is possible to adjust the quantity of sewage to whatever may be required and the rotation of the arm is also capable of being timed exactly. The outer end of the girder rests on and travels along a circular mono railway, supported on girders and pillars, and is driven by a 5 B. H. P. oil engine, geared to travel the circle in seven minutes. This is, as far as I know, the most perfect revolving distributor in the market, but it is too costly to become popular.

Aside from the expense of operating this apparatus, a heavy outer wall and a strong central support are required, and the first cost of the apparatus is also high.

Bed No. 4 was just being put under construction when I was at the works. It will be of crushed granite, one-half, in plan, of 1¼-in. stuff, with ½-in. material at the top, and the other half of 2½ and 1-in. material, respectively.

The drainage system may next be described, as it is similar, with the exceptions noted, for the single and double percolating beds. Every bed rests on a solid concrete floor. Bed No. 1, as already stated, has no drains save those formed by the interstices in the bottom layer of large blocks of slag. All the other beds have a practically solid false floor of drainage tiles. In circular bed No. 3 these tiles are flat inverted channels, but flat tiles, it is said, are unsatisfactory, because they are more liable to warp, and thus give a less firm bearing, and also because they allow deposits on their upper surfaces, and because they are costly. To obviate these defects semi-circular tiles, with broad footings and end lugs, are used. These tiles are molded to a thickness of 1 in., an inside diameter of 6 ins., and a length of about 6 ins. The footing projects ½-in. on either side and end, so the tiles are 12 ins. wide and 6 to 7 ins. long over all. The lugs at the crown and extension of the footings of one end insure open joints. The tiles are salt-glazed, which, it is said, reduces the tendency to harbor fungoid growths. Other claims for these tiles* are that they are stronger than those with perforations; that they assist largely in ventilating the beds, and that they conduce to freedom of drainage, without clogging from either the suspended matter in the sewage or from disintegrated bed medium, such as that from furnace clinker. The latter claim might be of great importance at some sewage works in England, but it

*Known as the "Bryan Patent," and made by R. H. Mansfield, Church Gresley, near Burton-on-Trent.

should be noticed that the bed material employed here has been selected with a view to permanence.

The three primary percolating beds, which, it should be remembered, are quite independent in operation from the circular beds already described, have an area of one acre each and a depth of 5 ft. The one secondary bed will be of the same size and depth as the primary beds.

The material composing each kind of beds will be broken Staffordshire bricks, which are very hard. The sizes and arrangement of the material in the primary beds, from the bottom upward, is to be 2½ ft. of 2½ to 3½-in., 1½ ft. of 1¼-in., and 1 ft. of ½-in. For the secondary beds the medium will be 1¼ to ¾-in. throughout.

The distributors for both the primary and secondary beds will be a system of piping, supported by flat chairs laid on the surface of the beds. The pipe will be provided with sprinkler nozzles, placed 10 ft. apart on each line of pipe, and the lines of pipe will be 10 ft. apart. After allowing for friction losses, the head on the sprinkler nozzles would be about 7½ ft. The maximum discharge capacity of this sprinkler system is figured at 413 Imp. gallons per sq. yd., which is about 2,000,000 Imp., or 2,400,000 U. S., gallons per acre.

The sprinkler system will be so arranged that each acre-bed can be operated in nine sections, thus making it possible to shut off portions of each bed for resting or cleaning. It is expected that some cleansing may be necessary on the primary beds, but that, at most, the top layer of the secondary beds will require turning at long intervals.

The proposed rate of application of sewage to the various beds, including those for both single and double treatment, is 1,000,000 Imp., or 1,200,000 U. S., gallons per acre, but it should be remembered that this is for sewage that has had sedimentation, septic treatment, double screening, and a second sedimentation in Dortmund tanks.

A few more words about the sewage farm may be of interest. The geological formation here is the Upper Triassic. The subsoil varies from clay and marl to gravel and sand, and there are about twenty acres of peaty land. The top soil is 6 to 26 ins. deep, but the latter depth is largely humus, the result of burying sludge in the earth.

The land occupies the Tame Valley for a distance of some six or seven miles. Of the 2,830 acres 1,784 are used for irrigation, and

on 407 acres of this it is necessary to pump the sewage; 229 acres are taken up by roads, streams, buildings and gardens and unirrigated strips adjoining public roads; 782 acres, all above the gravitation level, are used solely for ordinary agricultural purposes and for maintaining a healthy stock.

As a result of recent records, Mr. Watson states that in the interests of sewage purification he places certain crops in the following order: (1) Grass; (2) mangel-wurzels; (3) kohl rabi; (4) cabbages; (5) rhubarb; (6) turnips.

Steam plowing is considered absolutely necessary to give the depth and aeration of soil required on a sewage farm worked as hard as is this one. To facilitate the process the land is laid out as nearly as possible in squares. By preference, the roads should not be more than 1,200 ft. apart. Steam harrows are also required, both to break down the heavy furrows left by the plow and to root up the weeds, which, Mr. Watson says, are, and he fears will continue to be, the plagues of a sewage farm.

The average purification of the sewage on the farm in 1901, including the work done by the septic tank, was 88%, in 1902 90%, and in 1903 92%, based on the oxygen absorbed.

Mr. Watson states that "hard work and less regard for appearance" accounts for the difference in results obtained on the Tame Valley and other farms in England and Germany. By hard work, he says, is meant frequent application of sewage, frequent steam plowing to a depth of 21 ins., and less frequent cycles of rest than are common elsewhere. And by less regard for appearance, he means a large proportion of intermittent filtration area to land under crops.

Intermittent filtration areas are "laid out on fallow land, as nearly level as possible," or on sloping areas provided with low banks on contour lines. So far as may be the sewage is applied to these areas once in three days, thus making the operations similar to contact beds, "with this difference, that they are necessarily of greater area and more difficult to keep in sanitary condition."

This description of intermittent filtration, as practised in England, is well worth noting, because it shows the great contrast between the process as applied there and in America. In England, it will be seen, the process is little more than the application of sewage to a selected, carefully drained portion of a sewage farm

which has been plowed and lies fallow, while intermittent filtration in America is practised on carefully prepared beds of sand.

The remedy for "sewage sickness" on an intermittent filtration area in England, Mr. Watson says, is rest and a crop of "corn" or small grain. After three months of use, he states, intermittent filtration areas are "essentially offensive to the eye, and sometimes to the nose."

On the Birmingham sewage farm 3 and 4-in. drains are "formed of truly cylindrical tubes, laid on perfectly even gradients," 30 ft. c. to c.; and on the newer portions, "laid, as far as possible, to communicate with leader drains at both ends, in order to secure ventilation." Covered carriers have also been used of late, both to maintain the temperature of the sewage and to keep up the hydrolytic action begun in the septic tanks. A third reason for covered carriers, "which to some extent arises out of the second, is to keep down smell."

The sewage farm really comprises eight separate farms in one. At one of these I saw large, airy cow barns, with separate feed and water troughs, lined with white enamelled brick. Workshops for various classes of work were also seen.

The grounds at the septic tanks are being laid out with drives, walks, grass, shrubs and flowers.

I visited the sewage farm and works on a cool, windy day, after rainy weather. No odor was noticed, except a slight one where the septic tank effluent was rushing into the main carrier. Some of the intermittent filtration area, which had been used through the winter, was covered in depressed sections with sludge and green slime, thus bearing out the statement by Mr. Watson quoted a few lines back.

I was particularly impressed by the manner in which Mr. Watson referred to operations which he expected to perform far in the future, showing the certainty of tenure of municipal office in Great Britain, as compared with the United States.

As may have been concluded by the reader, Mr. Watson is not a believer in contact beds. He thinks them less permanent and of less capacity than percolating beds; neither does he believe in covered septic tanks, which he considers unnecessary and dangerous. He is seeking a permanent material for his percolating beds, for which he certainly deserves commendation.

A few interesting projects at these works are still unmentioned. The chief of these is the construction of a refuse destructor at the site of the septic tanks, combined with an electric generating station. The electric current will be used for operating various machinery at the works and on the farm, including the sludge screens, already mentioned; sludge pumps, pumps to lift sewage to levels which cannot be reached by gravity, driving farm machinery and lighting. The electric motors and pumps will replace the portable boilers and pumps now in use.

The destructor naturally falls within the province of another department, and its first cost, I understand, will be charged to the cleansing or sanitary department, but the power pumping station will be operated by the drainage board.

CHAPTER XIV.

Chemical Precipitation with Sludge Disposal at Sea, Roughing Filters, and Percolating Filters with Spray Nozzle Distributors at Salford.

The sewage works at Salford are unique for their combination of (1) chemical treatment, (2) rapid filtration or straining and (3) continuous filtration or percolation through one large bed on which sewage is sprayed through nozzles set in stationary pipes. The chemical precipitation works were put in operation in July, 1883, but until 1890 they were not operated nights and Sundays. The roughing filters and bacteria beds were put in operation in March, 1902, and have since then been in constant use. Since 1892 the works have been under the charge of Mr. Joseph Corbett, Borough Engineer of Salford, who conceived and executed the continuous percolating filters and the other changes in the works, but who appears to have been hampered by a council or council committee which has not given him a free hand.

Salford is a large manufacturing borough with a population of 220,000 and an area of 5,202 acres. It adjoins and to a stranger cannot be distinguished from Manchester.

Salford obtains its water supply from Manchester. Its sewers are on the combined system and about three-fourths of the sewage is pumped to a height of 30 ft. The borough is divided about half and half between water closets and the pail system and middens. More water closets, Mr. Corbett said, would be advantageous, because they

would reduce the present large proportion of trade wastes from dye and other works.

The daily dry weather flow of sewage is 8,000,000 Imp., or 9,600,000 U. S., gallons, the average flow is 12,000,000 Imp., or 14,400,000 U. S., gallons, and the works were designed to treat a storm flow up to 38,400,000 U. S. gallons. The portion of the sewage that is pumped is screened through a triple set of screens mechanically cleaned, and the deposit in the screening chambers is lifted out by bucket dredges and deposited in the sludge tanks.

Lime and copperas are used as chemical precipitants, perhaps 3.33 grains of lime and 1.66 grains of copperas per U. S. gallon, but recent variations in the methods of treatment make it impossible to state the quantity definitely. The chemical apparatus is in duplicate and includes four lime slaking pans, two lime mills and two copperas tanks. The lime slaking pans are equipped with disks having rough teeth on their under side. The disks are suspended from the rim of a cog-driven horizontal wheel and break up the lime in the pan. The lime mixing pans are of the mortar mill type and have large rollers, to keep their axles and bearings above the lime and the sewage used to mix it. A 6-ft. screw, like a propeller screw, is placed in the chamber where the chemicals are mixed with the sewage. Two 20-I. HP. engines, one in use, are provided to operate the machinery at the plant.

Beyond the mixing chamber are two silt channels, 10 ft. wide and about 14 ft. deep, the first one being 100 ft. and the second, beyond the first, 50 ft. in length. These channels are located between the two sets of precipitating tanks. There are ten precipitation tanks, each about 110 ft. x 80 ft. in plan and with a normal working depth of from 6 to 9 ft., giving a total holding capacity of 5,000,000 Imp., or 6,000,000 U. S., gallons. The tanks are operated on the continuous flow plan, but alterations are in progress, designed to permit operation in series, like Hoffman kilns, or as separate tanks.

The grit and sludge are sent by gravity to sludge tanks, from which the mass is pumped into a vessel of 600 long tons' capacity and taken out to sea. With the sludge now being produced there is mixed old sludge from a ten-years accumulation near by. Last year the vessel carried 230 loads to sea, including new and old sludge. The density of the combined sludge was from 20 to 30%, but the pumps handled it without any trouble.

The effluent from the precipitation tanks flows by gravity to six roughing filters having a combined area of 18,360 sq. ft. The filtering material is 2 to ¼-in. gravel mixed, and the sewage is applied to a depth of 4 ft. above the surface of the beds. Mr. Corbett would have chosen, could he have had his way, 18 ins. of gravel, graduated from 1 in. at the bottom to 1-16-in. at the top, and to clean the gravel he would have used a grid of air pipes, supplied by a 10-HP. Root blower, a second blower being provided for use in case of emergencies. The gravel would then be washed two or three times a day, when the flow was heavy. Upward washing was provided for the filters, but at the time of my visit, on April 13, 1904, top washing was being used and men were forking over the gravel. The foreman said that the beds were so badly clogged that he could not wash them from below. When treating only the dry weather flow these filters are worked at some 20,000,000 U. S. gallons an acre.

One reason for adopting the percolating filters at Salford and also for omitting division walls and for going to so much expense for a sprinkler distributing system was the scarcity and costliness of land. The city owned but 34 acres of land, and of that 12 acres was already occupied by the chemical precipitation works and accessories before the percolating beds were built.

Approximately 26,000 sq. yds. or 5½ acres of filtering area has been constructed in bays 31 ft. wide and about 500 ft. long. The bays are formed by the drainage and sprinkler systems and not by division walls. The mean depth of 13 of the bays is 5 ft. and of two of them 8 ft. They are composed of clinkers, screened in a plant owned by the borough. The rough clinkers cost about 63 cts. per cu. yd., but nearly half of their bulk is lost on screening.

The main distributing pipes are of 15 to 6-in. cast iron, 31 ft. c. to c., with their bottoms 18 ins. above the concrete floor of the beds. From these horizontal pipes vertical ones rise to supply and support a series of 4-in. flanged and bolted horizontal pipes at right angles to the main pipes, 10 ft. c. to c., and only a few inches above the surface of the filtering material. Six spray nozzles are set in the 31 ft. of length of these pipes, each nozzle serving 5¾ sq. yds. of area. Besides the vertical pipes, the sprinklers have as supports tie rods extending out about 10 ft. from each end and running over girders placed above the vertical pipes. These girders also serve as supports for railway track; a single rail and a double line of rails, alternately. The rails forming the double line are 2 ft. apart, and on them small cars

were run for putting in the filtering material. Mr. Corbett proposed to utilize the single rails and one of the double rails to carry a mechanical apparatus to clean or stir the surface of each bay of the beds, but thus far he has not been permitted to do so. He was of the opinion that for the best results the surface of the filtering material should be stirred daily, and was about to try an ordinary harrow for that purpose.

The drainage system, which rests on a 6-in. concrete floor, consists virtually of a false floor of flat-topped tiles on legs. The top of each tile forms an equilateral triangle 14 ins. on a side, and the tiles are 2 ins. in vertical thickness, perforated, and rest on three 4-in. legs, making a total height of 6 ins. There is a space of about ½-in. on each side between the tiles. Beneath each second main distributing pipe, or 62 ft. c. to c., there is a concrete culvert 2 ft. wide, 4 ft. high, with a nearly square internal section, pierced with ports 4 ins. sq. and 12 ins. c. to c., corresponding to the openings between the legs of the drain tiles.

The cost of the percolating beds, complete, including piles beneath the vertical pipes and a wall enclosing the beds, was 33s., or $8, per sq. yd., which is £7,986, or $38,800, per acre of effective area.

About 3,400 sq. yds., or 0.7 acres, of bed was being built near the large bed at the time of my visit, presumably as the beginning of a second large bed.

I found only one bay of the percolating filter at work, and the nozzle pressure on it was too light to show it to good advantage. This was apparently due to the clogged condition of the roughing filters. To exhibit the full effect of the spraying nozzles, effluent directly from the precipitation tanks was turned on, and made a fine display. The odor on the leeward side, however, was quite strong, and suggested that the spraying might be advantageous for the removal of gases, provided there was no one in the neighborhood to be disturbed by the odor. The conditions may have been such as to give an unusual odor, as it was evident that the plant was not in good working order.

Mr. Corbett stated that chemical precipitation removes 50 to 55% of the organic matter, as indicated by the oxygen test, and that during the previous weeks the precipitation tanks, roughing and percolating filters combined, had reduced the oxygen consumed by 90%, but the beds had not been hard worked. He remarked that during the same week the final effluent from the 8-ft. bays

showed 0.27 and from the 5-ft. 0.39 grains of oxygen per Imperial gallon, in a four hours' permanganate test, as compared with the Mersey & Irwell standard of 1 grain.

Mr. Corbett believed that when the chemical precipitation tanks had been reconstructed and the roughing filters put into shape the works could give satisfactory results up to four times the dry weather flow, or up to 32,000,000 Imp., or 38,400,000 U. S., gallons a day. That would mean, for the present 5½ acres of percolating beds, a rate of about 5,835,000 Imp., or 7,000,000 U. S., gallons an acre a day!

In a mild climate, where land is scarce and sludge can be readily taken to sea, a combination like that at Salford might frequently have much to commend it, and it is much to be hoped that Mr. Corbett will yet have an opportunity to give his system a fair trial.

CHAPTER XV.

Septic Tanks and Percolating Filters With Revolving Sprinklers, for Accrington and Church.

Municipal coöperation is common in England. Accrington, a Lancashire borough with 43,000 population and an area of 3,426 acres, has joined with Church, a place of 6,400 population, in building sewage works, and with Church and several other small places in buying gas and water-works from a private company. Church and one of the municipalities interested in the gas and water-works own a cemetery jointly. Mr. W. J. Newton, Assoc. M. Inst. C. E., is surveyor of Accrington and engineer to the Accrington and Church Outfall Sewer Board. In the absence of Mr. Newton during my visit to the sewage works on April 15, 1904, I was shown about by Mr. H. C. Ritchie, assistant surveyor.

The sewers tributary to these works are on the combined plan. The dry weather flow is 1,250,000 Imp., or 1,500,000 U. S., gallons, and the joint board is supposed to treat four times this quantity, but at present the capacity of the works is limited to 2,500,000 Imp., or 3,000,000 U. S., gallons. A tract of land a mile below the present works has been acquired for the treatment of storm water on shallow beds. Accrington has changed from the pail to the water closet system.

The sewage works was put in operation in 1888, and conducted about ten years as a chemical precipitation plant. The system was then changed to open septic tanks and contact beds, but the latter gave way to percolating filters with revolving sprinklers.

When chemical precipitation was employed the sewage was passed through a grit or detritus chamber, provided with automatically cleaned screens, and with bucket dredges. The dredges are no longer used, but the brushes for cleaning the screens are run daily.

The tanks, now operated as open septic tanks, are six in number, practically equal in size, with an effective depth of 9 ft. and a combined holding capacity of 1,875,000 Imp., or 2,250,000 U. S., gallons, which is nearly twice the dry weather flow. The tanks are operated in sets of three compartments. It is said that in summer the scum on the tanks is strong enough to bear up a man. At the time of my visit some of the tanks were fairly well covered with a dark scum, which seemed to be composed of fine-grained material.

About once in nine months each tank is cleaned by first pumping its liquid contents into the other tanks and then running the sludge into a lagoon. The sludge, in boatloads of 50 long tons, is sold to a farmer, at a nominal profit of a half penny, or 1 ct., a ton; that is, the average price paid the borough is 12½ pence per ton, and it costs the borough 12 pence to deliver the sludge on the boat by means of carts. A cable railway, to cheapen the cost of handling, was constructed just after my visit, as a substitute for the carts.

The change from contact beds to percolating filters was the result of visits to other sewage works and various experiments. Ten of these percolating beds were built in or about 1899, and four (not all fitted with the same kind of sprinklers*) have been added since, making a total area of 4,522 sq. yds., or somewhat less than an acre. The average depth of the filtering material in the beds is 8½ ft. Six of the old and two of the new beds have six 60-ft. revolving sprinkler arms. The four new beds have 60-ft. arms, three having six and one four arms to a set. The other four old beds have four 40-ft. sprinkler arms. The beds are polygonal in plan,

*The sprinklers on the old beds are similar if not identical in design with the earlier Whittaker & Bryant sprinklers in use at several other sewage works. The name of the sprinklers has been changed to Candy-Whittaker and the makers now style themselves The Patent Automatic Sewage Distributors, Ltd., 4 Westminster Palace Gardens, London, W. C.

with two or more sides in common. Each set of beds is enclosed by a 9-in. perforated brick wall, and has a thick concrete floor, extending beyond the beds and to the outside of the enclosing walls. The walls of each bed are of brick checker-work; that is, have openings in them from the top nearly to the concrete floor. Underdrains of perforated pipe cover the entire bottom of each bed. The material composing two of the 40-ft. coke beds is clinker, and of the other twelve beds is gas coke 2 to 3 ins. in size.

Pulsometer pumps are used to force the sewage to the ten old beds and to operate the sprinklers. It was calculated that the steam used in the pulsometers would raise the temperature of the sewage 4° F., and be of advantage to the process, although the engineer and chemist claimed that it was not essential for efficient treatment. The four new beds are at a slightly lower level, and their sprinklers are driven by the natural head of the escaping sewage. Two of the sprinklers have their central rising pipe perforated so as to discharge into a drum connected with the sprinkler arms. The drum works in a mercury seal. With a head of 2 ft. the apparatus will deliver about 500 Imp., or 600 U. S., gallons per sq. yd. per day. It will operate with a much smaller head, but at a less rate. A third of the new beds is provided with a somewhat similar apparatus, devised by Mr. Newton, but without the mercury seal, and is a jointless, revolving distributor, which can be made to work at any head above 6 ins. The fourth new bed has fixed sprinkler pipes, laid on its surface, supplied by a siphon.

The sewage is continuously applied to the beds through the various sprinklers. The pulsometer gives a jerky motion to the sprinklers fed by it, and the spurts of the liquid help keep these sprinklers clean. The holes in the other sprinkler arms have to be cleaned by hand once a day. It is proposed to raise the walls of the septic tank so as to give the effluent from them a sufficient head to operate the sprinklers on the old beds without the use of the pulsometers, and the expensive production of steam, which indicates that the present management does not consider that there is any advantage derived from the heat imparted by the pulsometer.

The 4,522 sq. yds. of percolating beds are operated at a rate of 350 Imp., or 420 U. S., gallons per sq. yd. This would provide for 1,580,000 Imp., or 1,900,800 U. S., gallons a day, as against a dry weather flow of 1,500,000 U. S. gallons, and would be at the average rate of 1,700,000 Imp., or 2,030,000 U. S., gallons an acre. I was

told that the filtering material had never been renewed and that its surface is not stirred.

The effluent from the ten old beds flows into two small settling tanks, each 54 x 25¾ ft. x 2⅓ ft. deep, from which it overflows across a channel of white glazed brick and thence into the River Hyndburn, which is a tributary of the Ribble and thus under the Ribble Joint Committee. The settling tank is cleaned twice a week by pumping the sediment in it into a small lagoon. There is a like tank for the four new beds.

The manager of the works is a chemist and has a laboratory at the works. Samples for analysis were formerly taken daily, but only two samples a week are now examined.

Besides the manager the usual force at the works consists of one man at 30 shillings, or $7.30, a week, who comes to the works Sundays afternoons; a laborer at 5½d., or 11 cts., an hour for nine hours a day, and two "boiler men" at 35 shillings, or $8.50, a week for 12-hour days. At the time of my visit an extra laborer was employed. The weather then was very wet. No bad odors were observed.

Some of the unit costs of construction, given to me from records at Mr. Newton's office, were as follows: Brickwork, 8⅔ shillings, or $2.11, per cu. yd. of filtering material; half tile drains, 5 shillings, or $1.21; clinker, 3s. 7d., or 87 cts.; sprinklers, 1 shilling, or 24 cts.; total, 18¼ shillings, or $4.43, per cu. yd. of filtering material. The perforated drain pipes cost 2s. 10d., or about 69 cts., per lin. ft., and the checker-work walls around each bed cost at the rate of 5⅔ shillings, or $1.38, per sq. yd., measured on vertical faces.

CHAPTER XVI.

Chemical Precipitation and Various Experiments, Many on a Large Scale, with Septic Tanks, Continuous Percolating Filters, and Other Systems, at York.

York has been dealing with a sewage works problem for many years and has not yet settled it. Meanwhile it has been contributing materially to the rapidly accumulating fund of information on various so-called bacterial systems. Briefly stated, the city put a chemical precipitation plant in operation in 1894, and on being pressed by central authorities to proceed with the development of a land treatment system it concluded that the land previously bought for the purpose was entirely unsuitable for the reception of sewage and began to try

various so-called bacterial schemes. The latter have included open and closed septic tanks and contact, percolating and other kinds of beds. The net outcome thus far has been the conversion of two of the six precipitation tanks into open septic tanks, and the building of two large percolating continuous filters, fed by revolving sprinklers. These tanks and filters are still classed as experimental, but they are on an everyday working scale, and as compared with the other tanks and filters tried are relatively permanent in character. Mr. James Mansergh*, M. Inst. C. E., was engineer for the original works. The experimental work has been carried out by Mr. A. Creer, Assoc. M. Inst. C. E., City Engineer of York, who assumed office in 1889, after Mr. Mansergh had received instructions to prepare the scheme for a precipitation plant.

York has a population of about 78,000 and an area of 3,692 acres. The water supply, which is furnished by a private water company, is pumped from the River Ouse and is subjected to sedimentation and double filtration. The daily consumption is 39 Imp., or 45 U. S., gallons per capita. The sewers are on the combined plan. The daily dry weather flow averages about 3,500,000 Imp., or 4,200,000 U. S., gallons, and is pumped from the end of the gravity outfall sewer at Fulford to the precipitation works at Naburn, as is also an average of 1,370,000 Imp., or 1,645,000 U. S., gallons of storm flow. The excess of storm flow goes by gravity through storm overflows leading from the main intercepting sewers into the river at various points untreated. The minimum daily flow of the river is given as about 140,000,000 Imp., or 170,000,000 U. S., gallons. About half of the houses in York are provided with water closets. The privies for the other half are gradually being converted into water closets.

All the sewage treated at the disposal works has been previously screened twice: once through rough screens before it reached the pumps and again through finer screens at the end of the force main. Normally it takes the sewage about five hours to pass from the city to the disposal works.

Alumino-ferric is used as a precipitant, at the rate of about 5 grains per Imp. gallon for the dry weather flow and 3 grains for the storm and ordinary flow combined, or 4.17 and 2.5 grains per U. S. gallon, respectively. The tanks are 164 ft. long, 39½ ft. wide, and have an average working depth of 7 ft. This gives a holding capacity

*Victoria Street, Westminster, S. W., England.

of about 275,000 Imp., or 330,000 U. S., gallons. The tanks are worked on the continuous top flow plan. The sludge is now being buried near the disposal works, at the same time serving to raise the level of some low land. Large heaps of sludge have accumulated near by.

The chemical precipitation works had not long been in operation before the city was requested by the Local Government Board to prepare land for the further treatment of the effluent. It appears that this had been contemplated originally and that 18 acres of land had been provided for the purpose. The request was the result of a complaint by the West Riding Rivers Board that the effluent being turned into the river was unsatisfactory. Test holes dug in the land under the direction of Mr. Creer led to the conclusion that the land was absolutely unsuited to receive sewage. In October, 1897, the city applied to the Local Government Board for authority to borrow £2,500, or $12,150, for bacterial experiments, but after a hearing in March, 1898, the loan was denied, having been opposed by both the Rivers and the Fishery Boards. Apparently the two boards were determined that the land scheme should be carried out, but the sewage committee was convinced that such a proceeding would be a waste of money and might prove a nuisance. It was decided, on Mr. Creer's recommendation, to experiment with various so-called bacterial processes, and in April, 1899, a closed septic tank and single contact filters were put in use. Previously, chemically treated sewage was passed through the filters. Other tests, up to the close of August, 1901,* included the application of crude sewage to double contact beds; ladder filters, or a series of downward and upward filter beds, receiving crude sewage; open septic tanks, followed (1) by continuous percolating filters, (2) by double contact beds, and (3) by intermittent gravel filters (three sets of experiments); and covered septic tank effluent on graded and underdrained land forming a part of the 18 acres already mentioned. The ladder filters† receiving crude sewage and the land area receiving effluent from the closed septic tank were utter failures, and the intermittent filter receiving open septic tank effluent was little better. The land area, it may be added, was trenched 2½ ft. deep

*See special report on "Sewage Purification Experiments at the Naburn Disposal Works," by A. Creer, City Engineer, dated October, 1901.

†With the exception of the ladder filters, these tests were on a working scale. Each of the ten ladder filters was only 4 x 3 ft. 5 ins. x 2 ft. deep.

with spades, but experiments showed that the soil was, for all practical purposes, impervious to the effluent. Two areas of one-eighth acre each were devoted to this test. The closed septic tank and single contact beds did not give such results as were to be expected from similar installations elsewhere. Crude sewage on double contact beds was purified quite satisfactorily, but the volume yielded was considered low, the beds lost in holding capacity, which was partly remedied by resting periods of extra length, and the surfaces of the beds had to be forked over a number of times. The piping arrangements, however, were such that when the beds received crude sewage the velocity of flow in the main supply was suddenly increased and sedimentary deposits washed onto the beds. The same double contact beds, when subsequently treated to effluent from an open septic tank, showed rather less favorable results than with crude sewage, but apparently the first contact bed had been partly clogged during the earlier experiment. All things considered, it was felt in October, 1901, that open septic tanks and continuous percolating filters were most promising, and most worthy of further study. The combination gave an average purification of 84.5% by the oxygen absorbed test, and of 90% by the albuminoid ammonia test, the actual quantity of absorbed oxygen being 0.47 grains per Imp. gallon, and of albuminoid ammonia 0.051, as compared with the West Riding Rivers Board provisional standard of 1 grain of oxygen and 0.1 grain of albuminoid ammonia. The filtrate was non-putrescible and the filtering material showed no loss in liquid capacity, though renewal might become necessary. Finally, the continuous filters showed larger capacity per square yard than any other filters tested and therefore were considered to be well adapted to treat storm water.

As a result of the experiments just reviewed it was decided to confine further studies to the open septic tank and continuous percolating filter, except that the covered septic tank and single contact filter was continued in experimental use until 1902. The last-named combination gave no better analytical results in 1901-2 than formerly, but did give trouble through the sludging up or clogging of the filter surface.

From March 12, 1902, to May 7, 1902, the open septic tank and the filter were out of use to allow the construction of a grit chamber. This was formed by constructing a wall across the septic tank 10½ ft. from the inlet end. Previous to this the crude sewage had been admitted to the septic tank after a rough screening only.

Up to March 7, 1902, the tank and filter had passed 105,000,000 Imp., or 126,000,000 U. S., gallons of sewage, representing 464 Imp., or 557 U. S., gallons per sq. yd. per working day, or 426 Imp. (511 U. S.) gallons per sq. yd. per day for the whole period. The latter rate is equal to 2,060,000 Imp., or 2,437,000 U. S., gallons per acre. The sludge removed from the septic tank at this time was about 20 ins. in depth, representing 1 cu. yd. to some 270,000 Imp., or 324,000 U. S., gallons of sewage treated, or about one-ninth the proportion obtained by chemical precipitation. The material forming half the percolating filter bed was removed during this period. It was found that the lower 9 ins. of clinker and cinder had broken down to the consistency of fine gritty ashes; above that the material was sound, free from slime, but covered with fine grit. The disintegrated material was removed, the remainder put back, and the deficiency made good. Between the date of re-starting the filter on May 7, 1902, and November 4 of the same year eleven sets of analyses were made to show the relative efficiencies of the two halves of the filter. The purification effected by the disturbed side was 89%, and by the undisturbed side 91%, the results by both the oxygen consumed and albuminoid tests being reported as identical. The rate of filtration ranged from 288 to 515 Imp., or 346 to 618 U. S., gallons per sq. yd., rising quickly to the latter figure at the beginning of the period, but falling to 450 Imp., or 540 U. S., gallons near the close of the observations. The rate was subsequently reduced still further, averaging 380 Imp., or 456 U. S., gallons from Nov. 18, 1902, to March 22, 1904.*

To the close of March, 1904, this filter had been in operation three years and nine months, and had passed 210,000,000 Imp., or 252,000,000 U. S., gallons.

The net results of the tests up to April, 1904, as interpreted by Mr. Creer, seemed to be strongly in favor of septic tanks and continuous sprinkler or percolating filters. All the tests thus far made, including the small experimental tanks and filters, conversion of the two precipitation to septic tanks and the construction of two continuous filters, have been paid for from revenue, the Local Government Board, as already stated, having refused an application for a loan for experimental works. Naturally the city is averse to paying for further permanent works from revenue and at the same time is not inclined to

*These figures have been taken from a paper by Mr. Creer read at York, England, in May, 1904, before the Incorporated Association of Municipal and County Engineers.

hurry about applying for a loan when the loan for the precipitation works is still largely outstanding and every one is awaiting the report of the Royal Commission on Sewage Disposal.

Originally only one of the old tanks was converted into a septic tank. When the second percolating filter was added another of the old tanks was converted into a septic tank, but the two are worked as one, giving a combined length of 320 ft. These tanks have neither submerged inlets or outlets.

The first continuous filter was circular, 67½ ft. in diameter, and composed of clinker and cinder 6½ ft. deep, obtained from local furnaces and containing much soft material. The floor of the filter was made of concrete, with radial drainage grooves 1½ x 1½ ins. in section, reaching from the outer edge to within 3 ft. of the center. The center of the floor is 6 ins. higher than the outer edge, and the latter is surrounded by a shallow effluent channel 2½ ft. in width. The wall supporting the filtering material is of brick, 9 ins. thick and 8¾ ft. high, built up with pigeon holes. The clinker and cinder rest directly on the concrete floor. Embedded in the filtering material at each successive 2-ft. level from the floor are radial lines of 4 and 6-in. unglazed perforated pipe, 24 lines in all. These were designed to act as air ducts, but have proved very useful for taking temperature observations as well.

The revolving sprinkler is supported on an 8-in. cast iron central feed pipe. The sprinkler arms are capped at their ends and these caps are removed daily and the pipes swabbed out to keep the perforations open.

The new or second percolating filter is 100 ft. in diameter and is otherwise different from the first one. Its 8-in. floor, composed of concrete and old railway rails, slopes to the center, to retain both broken down bed material and suspended matter from the sewage. Pipes are provided to remove such deposits. A false floor is formed as follows: Radial walls 7 ins. high and 6 to 15 ins. apart, composed of pigeon-hole work, are laid on the concrete floor. On these walls expanded metal is placed to receive and support the bed material. The bed is enclosed by a 9-in. pigeon-hole wall of blue Staffordshire brick, laid in cement, carried to a height of 7½ ft. above the expanded metal. A radial channel and a channel outside and concentric to the outer wall collect the filtrate.

The filter is composed of four segments of unequal size, each filled, for purposes of testing, with a different kind of material. The

several materials and the relative number of cubic yards of each are as follows: Clinker, 1,492; hard, broken brick in large pieces, 312; honeycomb slag, 189; gas-coke, 189.

This filter was put in operation on April 29, 1903, and up to Feb. 23, 1904, had passed an average of 362 Imp., or 434 U. S., gallons per sq. yd. per day, which is equal to 1,752,000 Imp., or 2,102,000 U. S., gallons per acre. With sewage showing 5.8 grains per gallon of oxygen absorbed in four hours at a temperature of 80°, and 1.18 grains of albuminoid ammonia, the brick removed 89.6% of the albuminoid ammonia; slag, 90.4; coke, 93.4; clinker, 92.8%. The results as shown by the oxygen tests were a little higher, but relatively about the same for the different kinds of material. The following percentages of the mineral matter in the tank effluent were retained: Brick, 61%; slag, 61%; coke, 47%; clinker, 62%.

Analyses of septic tank liquor taken on two different days at different points in the combined length of the two septic tanks indicated that after passing a distance of 225 ft. there was no further reduction of albuminoid ammonia and oxygen consumed, and that the further reduction of free ammonia and solids, both mineral and organic, was not sufficient to warrant the additional 100 ft. or so of the length of the tank.

The effluent from the septic tanks, as I saw it on April 20, 1904, when I visited the works with Mr. Creer, appeared to be of a fair quality, but it contained a large amount of finely divided suspended matter. The effluents from the percolating filters, as seen in thin sheets in the outlet channels, looked well.

CHAPTER XVII.

Septic Tanks, Percolating Filters and Rapid Secondary Filters at Salisbury.

Salisbury is well known to archæologists for its proximity to Stonehenge, and to students of ecclesiastical architecture and all lovers of the beautiful for its cathedral and cathedral close. No one who visits the cathedral with its statue-covered west front and its lofty spire, set in the midst of one of the finest wooded lawns in all England, would for a moment suspect that only a few hundred yards to the south are such humble establishments as a sewage works and refuse destructor. This combined plant includes a number of interesting features: the two works are operated under the direction

of one manager, and the heat from the refuse destructor is utilized in boilers supplying steam to drive the sewage pumps. The sewage works have been remodelled and extended from a chemical precipitation plant to open septic tanks and percolating beds, some with revolving and some with fixed sprinklers, and following these the sewage is applied to small filter beds.

Although Salisbury is an old city, its population is only some 18,000. Its area is also small, being only 600 acres. Application for an extension of area, with a consequent increase in population, was recently made to the Local Government Board, and raised questions regarding the failure of the sewage works to comply with the Board's requirements (formerly more rigid than now) that all so-called bacterial methods must be supplemented by the treatment of the effluent on land. These questions, combined with a possible addition of population tributary to the works, partly account for the discrepancy between the volume of sewage and the capacity of the plant for its treatment. That plant, it should be stated, was built independently of the Local Government Board, as may be done either by paying the cost of construction from yearly revenue to repay a loan on a mortgage of the works, or from a loan authorized directly by Parliament.

Salisbury owns and operates its water-works, which take a supply from the chalk by pumping. The average daily water consumption for all purposes is 38 Imp., or about 45 U. S., gallons. This includes 16 Imp., or 19 U. S., gallons used by the railways.

Sewers on the combined plan were built in Salisbury as far back as 1853. Some of the early sewers, where in low, wet land, were laid with open bottom joints, for subsoil drainage. Recent extensions have been made on the separate system, and a conversion of the older sewers to that system has been proposed. Such a step might perhaps reduce the dry weather flow to 540,000 Imp., or 648,000 U. S., gallons a day, as compared with a present minimum of 2,000,000 Imp., or 2,400,000 U. S., gallons, and a maximum of 9,000,000 Imp., or 10,800,000 U. S., gallons. The capacity of the purification works is given as about 1,750,000 Imp., or 2,100,000 U. S., gallons a day, and the average amount pumped is reported as 3,000,000 Imp., or 3,600,000 U. S., gallons. All of the latter is passed through the septic tanks, but only some three-quarters of it can as yet be treated by the bacterial beds. Everything reaching and passing the works is finally discharged into the River Avon.

Chemical precipitation works were built here in 1884, and continued in operation until they were remodelled, beginning, say, early in 1901, to receiving and detritus tanks, septic tanks and percolating beds. Coextensive with these changes the refuse destructor already mentioned was built and new pumps were put in. Mr. A. C. Bothams, Assoc. M. Inst. C. E., City Surveyor of Salisbury, was engineer for all these improvements, and Dr. Samuel Rideal* was consulting chemist.

Mr. John Hamlin is manager of the combined sewage works and refuse destructor, and has been in the employ of the city for twenty-five years. Mr. Bothams succeeded his father, who was for fifty years city surveyor of Salisbury. These are notable instances of the long tenure of office common in British municipalities, a practice that plays no little part in the success of British municipal undertakings, and that might well be more generally adopted in the United States.

The sewage comes from the city by gravity to a screening chamber perhaps 6 ft. wide and 30 ft. long, provided with inclined iron screening bars for its whole length, and flows thence for a short distance to four receiving tanks, which can be connected with each other, having a combined capacity of about 500,000 U. S. gallons. From these tanks the sewage is lifted 13 ft. to the septic tanks. There are two pumps designed for working each at a range of from 2,000,000 to 5,000,000 Imp., or 2,400,000 to 6,000,000 U. S., gallons per day, driven by horizontal compound triple-expansion Worthington engines. Only one pump is used at a time, and at present it is not worked to its full capacity. There are two open septic tanks, with trapped inlets and outlets, having a combined capacity of 1,000,000 Imp., or 1,200,000 U. S., gallons. The tanks have the usual depth of 16 ft., due to their having been remodelled from the old precipitation tanks so as to give a sufficient height to command the percolating beds without a second pumping. Both the receiving reservoirs and septic tanks have the same ground plan as the old precipitation tanks.

It is said, as already stated, that about three times the holding capacity of the septic tanks, or a total of 3,600,000 U. S. gallons daily, is passed through them. The sludge has been removed from the tanks once since they were put in operation, but the cleaning was for the purpose of making new pipe connections. It is antici-

*Analytical and Consulting Chemist, 28 Victoria St., Westminster, S. W.

pated that the volume of sludge to be removed will be about one-tenth of that usually obtained by the old precipitation works.

From the septic tank the sewage flows to five percolating beds, locally known as the Adams* and the Stoddart† continuous flow beds. The Adams beds are three in number, circular in plan, and are provided with revolving sprinklers, automatically worked by the 2-ft. fall of the liquid treated. The two Stoddart beds are rectangular in plan, have fixed distributors, and do not require the 2-ft. head or fall.

Each bed of each kind has an area of 500 sq. yds., or something over 0.1 acre, and an average depth, from which there is but little variation, of 6 ft. above the drains. All the beds have solid concrete floors, sloping slightly toward the outer side. On the concrete ordinary 4½x9-in. bricks are laid on edge, with spaces about 2 ins. between each row, thus forming underdrains extending from the center of the circular beds and the central line of the rectangular or Stoddart beds to the outer side, and making it possible to flush out the floor of the bed by means of a hose or by flooding with the applied septic effluent.

Large pieces of clinker are laid directly upon the brick underdrains and are also used to form the outer walls of the bed, which are laid dry, with a slight batter. The clinker composing the body of the several beds is mostly 2 to 3 ins. in its largest dimension, with some smaller and some larger mixed in. About half of the clinker came from the gas works and cost about $2.25 per cu. yd. at the sewage works, screened. The other half of the clinker is from the adjoining local refuse destructor. The two kinds of clinker are used separately, but no difference in the results given has yet been noticed. The destructor clinker is more irregular in shape and more honeycombed than that from the gas works. Before putting the clinker into the beds it is washed with effluent from the septic tanks, which, as compared with unwashed clinker, reduces from six to three weeks the time required to bring the beds to maturity.

The Adams distributors consist of four radial perforated tubular arms, revolving on and fed from a support at the center of the

*S. H. Adams, Assoc. M. Inst. C. E., York, England, and Managing Director of the Adams Hydraulics Co.

†F. Wallis Stoddart, City Analyst, Bristol, England. Mr. Stoddart calls these beds Stoddart continuous filters.

bed. The tubes are perhaps 5 ins. in diameter at the inner and 3 ins. at the outer end, and the perforations may be 3/8-in. in diameter and 3 ins. apart.

The Stoddart distributors, which it will be remembered are stationary, on rectangular beds, have as units a piece of specially corrugated sheet iron about 20 ins. wide and 6 ft. long. The corrugations are made very sharp, to give greater rigidity to the sheets. In the ten ridges small notches, 2 ins. c. to c., are cut, and in the holes in the eleven channels there are set, with heads pushed home, nails 3/4-in. long, 1 in. c. to c. The sewage trickles down and drops from the nail points. These units are placed at right angles to and on either side of feed pipes, and only a few inches above the surface of the beds. Half of the area of each bed, more or less, is thus covered with distributors.

All the beds are operated continuously. The oldest bed had been in use for about eighteen months; the newest had just been completed at the time of my visit (April 8, 1904).

Mr. Bothams stated that the Adams bed is operated at the rate of 900 Imp. gallons per sq. yd. and the Stoddart at only 400 gallons, to attain practically the same results, the comparison of results being based on visual inspection and analyses. Even 400 Imp. gallons per sq. yd. is at the rate of 1,936,000 Imp., or some 2,300,000 U. S., gallons per acre, which would be a moderate rate of filtration for an ordinary slow sand water filter, and is high for such a relatively foul liquid as septic tank effluent.*

I was informed that there was the expectation of discharging the effluent from the percolating beds directly into the River Avon, after the removal of such sediment as would be retained in a sump channel, but that it was found necessary to arrest small gritlike particles in suspension. This was provided for by building shallow secondary beds. When the works came under the jurisdiction of the Local Government Board, on application being made for an extension of the borough limits, a change in plan had to be ef-

*In a letter to the author Mr. Stoddart states that the low rate at Salisbury is due to: (1) Failure to wash and grade the clinker forming the bed. (2) Unequal application of the sewage to the bed, on account of a poor levelling of the top of the bed and of the joists supporting the distributors. These defects have been guarded against, Mr. Stoddart says, in later installations of his system. He also states as his belief that his system, as now improved, would be able to treat Salisbury sewage at the rate of 1,500 Imp., or 1,800 U. S., gallons per sq. yd. per day.

fected, and additional shallow secondary beds were arranged for. Stakes had been set, at the time of my visit, for a fourth Adams revolving sprinkler bed, but everything was in abeyance pending the decisions of the Local Government Board as to the annexation of territory to the city and the enlargement of the sewage works to meet present and future needs.*

The secondary beds thus far provided for were constructed as follows: A main drain 15 ins. in diameter and 4-in. drains, herring-bone style, 7 to 8 ft. c. to c., were laid in shaped trenches, with their tops flush with the natural earth bottom of the beds. Broken clinker, graded from 3 ins. in largest dimension at the bottom to dust at the top, was placed over the drains to a depth of about 18 ins.

The combined area of the present percolating Adams and Stoddart beds is only 22,500 sq. ft., or a little more than half an acre. The shallow secondary beds must have an even less area. They appear to be operated somewhat like our American intermittent filters, but at many times the rate of the latter. They are soon clogged with fine sediment in a layer sometimes ½-in. thick, which is removed by raking or scraping. The effluent from one of these beds I noted as being quite clear, except for a slight milky appearance and a little fine sediment. No odor was observed at the works, which are 575 ft. from the nearest houses in one direction and 650 in another, while on the other two sides practically no houses are in sight.

No separate account is kept for the operation of the sewage works and refuse destructor. Labor is interchanged, and one manager, who lives in a cottage on the ground, attends to both plants. The total working expenses of the two departments are about £1,200, or $5,800, per annum.

The many changes already made and still to be made in these sewage works, combined with the local conditions which have occasioned them, illustrate alike the unsettled condition of sewage treatment in Great Britain to-day and the difficulty of drawing conclusions from those works which shall be applicable to the design of sewage works in the United States.

*I have since been informed that the Local Government Board has approved these works, subject to their enlargement so as to provide for three times the dry weather flow of sewage and a similar quantity of storm water. The usual requirements as to the provision of land treatment of the effluent will in this case not be enforced by the Board. The old sewers, admitting subsoil water, must be altered so as to exclude it.

PART III.

SEWAGE FARMS.

CHAPTER XVIII.

The Reading, Sandhurst Military Schools and Aldershot Camp Sewage Farms.

For some years past nearly all the printed matter relating to sewage disposal in Great Britain has either contained no reference to sewage farms or else has spoken of them as being abandoned as rapidly as possible. The chief exception to this was a defense of sewage farming* made two or three years ago before some public gathering by Lieutenant-Colonel Alfred S. Jones, Assoc. M. Inst. C. E. Among my various letters of introduction I was most fortunate in having one to Colonel Jones, who very kindly took me to see three sewage farms, besides a fourth sewage works† where sewage farming has been abandoned for so-called bacterial beds. Two of the farms visited are managed by Colonel Jones, who also has one or two others in his charge, all under the War Office.

THE READING FARM.

This farm now comprises 869 acres, of which 450 receive sewage and 380 are underdrained. It was laid out some thirty years ago by Mr. James Mansergh, M. Inst. C. E., and for the past fifteen years has been in charge of Mr. Thomas Chettle, as Farm Manager or Bailiff. Mr. W. M. Colebrook is Chairman of the Council Committee responsible for the farm. Mr. Chettle lives in a comfortable house on the farm, which also shelters the farm offices.

Reading, which lies between London and Oxford, has a population of about 72,000. Its area is 5,278 acres, and its sewers are on the separate plan. Some of the early sewers were laid with clay joints, and admit ground water more freely than do the others. The maximum daily flow of sewage is given as 2,750,000 Imp., or

*This defense and a paper by H. Alfred Roechling, M. Inst. C. E., on a kindred subject was published in book form under the title "Natural and Artificial Sewage Treatment." (London and New York, 1902.)

†Aldershot Town; see Chapter XII.

3,300,000 U. S., gallons, and the minimum as about 2,130,000 Imp., or 2,500,000 U. S., gallons. Judged by its looks, the sewage is stronger than that of most American cities, and well broken up in its flow to the farm, which flow is mostly due to gravity. My visit, I may add, was made at about 3 p. m., on the afternoon of Tuesday, March 29, 1904, just after a heavy shower, preceded by a long, wet winter. The day was cool, and although much of the land was very wet, I noticed scarcely any sewage ponding. The apparent freedom from ponding and "sewage sickness" indicated that the land was well graded and the sewage carefully applied.

The effluent from the farm goes to the Kennett River, a small headwater of the Thames, and therefore under the jurisdiction of the Thames Conservancy Board. An inspector from the Board visits the farm frequently, but at irregular intervals. In a recent year the visits numbered 32, and in another 47. Samples for analysis are taken in duplicate from four points once every two months. The duplicate samples are left with the Reading authorities. Copies of the results of the analyses are not sent to the municipal authorities unless requested or unless the effluent is bad.

Since Christmas, 1903, the farm has suffered from four heavy floods and two light ones, the worst of which flooded 600 acres of the farm. No such bad floods had occurred previously since 1894, but apparently much of the land, even in years of low water, is not sufficiently above the river to give the best results. Many of the underdrains are quite near the surface, and much of the time they are under water.

The staple product of the farm is milk, which is sold to Reading retailers at a yearly average price of about 9d. per Imp. gallon, or about 3.75 cts. per U. S. quart. There are now nearly 300 cows on the farm. Horses for farm work are home bred, and Mr. Chettle appears to be deeply interested in horses and horse breeding.

The main forage crop is Italian rye grass, which is sown anew once in two years. Four to six crops of this grass are cut each year. The first crop was to be cut soon after my visit, but to me it seemed very short; perhaps the shortness was due to the long wet winter. Large quantities of mangel-wurzels are also raised to feed to the cows.

An average of 70 men and boys are employed on the farm, running to 100 in harvest time. Practically all the reaping is done by hand, as much as possible by the piece. The rye grass is also cut

by hand. The regular weekly wage for men permanently employed is 16 shillings, or $3.89, besides house and garden and 80 shillings, or $19.44, extra at Michaelmas. Men employed by the day are paid 3 shillings each, with an extra shilling for cutting grain, and 4d., or 8 cts., per hour for overtime. The hours for these men are from 7 a. m. to 5 p. m. in winter, and from 6 a. m. to 5:30 p. m. in summer.

There are 23 cottages on the farm, with perhaps an average, including boarders, of 8 persons in each. Mr. Chettle stated with pride that during the last 15 years there had been only one case of typhoid fever on the farm.

The farm has shown a profit in some years, but on the whole it has been run at a loss, and the loss, instead of being charged to the net cost of sewage disposal, and met by taxation, has been carried as a debit balance in the hopes of better profits in the future. A reform in financial methods is now under consideration, including not only an adjustment of the deficit, but also a broad study of the administration of the whole farm, with a view to improved financial results. The council committee in charge of the farm visited Manchester with a view of judging the advisability of adopting so-called bacterial methods of treatment, but it finally concluded to make the most of its large sewage farm. To aid it in this matter it has appointed an advisory committee, consisting of Colonel Jones, who is chairman of the committee; Mr. Arthur Avis, manager of the Nottingham town sewage farm, and Mr. B. W. Farmer, of Little Bidwell, Berkshire, a farmer and land owner who has some 20,000 acres of land under his charge. Among other things, this committee will probably recommend that sewage be pumped to some high land not otherwise available for the reception of sewage.

I take it that this farm is an admirable illustration of some of the difficulties in sewage farming in England: (1) only a little more than half of it is under sewage, and a large portion is subject to the evil effects of high water; (2) there has been a tendency to place farming profits before sanitary sewage disposal. I thought it evident, from conversation with Mr. Chettle, that he much preferred farming without sewage to farming with it, and that he was interested mostly in stock breeding. I hope we may learn in America what comes of the deliberations of Colonel Jones's committee and its recommendations. I am inclined to think that his strong personality, combined with his admirable management of the two

near-by sewage farms described below, and the fact that he is on the managing board of a large hospital at Reading, have all combined to influence the Reading authorities to continue their sewage farming operations a while longer, instead of turning to septic tanks and contact or other artificial methods of sewage treatment. Credit must also be given to Mr. Chettle's farm management and to the courage and enterprise of the Reading authorities, who, besides building up their large sewage farm, have many other municipal undertakings in hand.

THE SANDHURST MILITARY SCHOOLS FARM.

This tidy little farm of only 13 acres receives the domestic sewage of about 1,000 persons, composing two military schools in the Parish of Sandhurst. Practically all this land is under sewage. The underdrains, which are laid to a depth of 2 to 3 ft., discharge into the Blackwater River, included in the Thames drainage system.

The sewage is received in two small concrete deposit tanks, used alternately, each perhaps 6 ft. wide, 15 to 18 ft. long, and from a few inches to 3 ft. deep. The sewage enters the deeper part of the tanks and discharges in a thin sheet over a level space at the shallow end. The sludge settles in the deeper part of the tank, from which it is removed about once a week onto adjacent land, where it is retained by a rough, low embankment until it has partly dried out.

Most of the regular work on this farm is done by an old man, whose wage is 4 shillings, or about $1 a day, and the use of a tiny cottage in addition. The cottage is entered through as tiny a front garden, and a large part of one side of the brick wall of the building was covered by the cherry red blossoms of a creeper. Notwithstanding this poetic exterior, the living room of the cottage seemed damp and close, and suggested the desirability of higher ground.

Italian rye grass, oats and mangel-wurzels are raised on the farm and sold to the Aldershot Camp, near by, or to other purchasers. Horses and laborers come from the Camp to do the plowing and like work, and a gypsy boy was engaged, at the time of my visit, to scare away rooks from a newly sown oat field.

The effluent from the underdrains was clear, and, except for one or two light whiffs as I went over the farm, no indication of sewage was noticeable. Colonel Jones has managed this farm since 1896, and it was a pleasure to see how well everything seemed to have been conducted.

Aldershot Camp Sewage Farm.

As has been well said, this farm may serve to illustrate the results of both good and bad management. Originally laid out in 1865, it was operated for nearly 15 years with satisfaction; then was badly managed for about an equal period, under a lease to a dairyman. Colonel Jones took charge of the farm in 1895 and again put it in excellent condition. The good and the bad management represent the extremes of sewage farming as a sanitary operation and as a means of profit alone. Perhaps no one thing has contributed more to good results here than the care exercised in grading the land and in laying out the distributing channels, both of which are treated by Colonel Jones as engineering problems. In fact, his whole management of the farm shows the mind and directing hand of the engineer.

The Aldershot Camp Farm, as it is generally called, now includes 132 acres of land, of which 121 acres are available for irrigation, having been underdrained to a depth of 3 to 6 ft. The land was originally a waste place of deep sand, and it is close by a military hospital. The managers of this hospital had been working for the abandonment of the farm, prior to the time Colonel Jones took hold of the latter, but are now, it is said, quite satisfied to have it almost beneath their windows. The population of the Camp varies from 20,000 to 30,000, besides which the drainage from stables for some 2,000 horses goes to the farm.

The sewage from different parts of the Camp is received at three points in deposit tanks similar to the one at Sandhurst, but larger, and having before them small grit or detritus chambers. The deposits in these chambers are stirred two or three times a day, to reduce the amount of organic matter retained therein. One set of deposit tanks, remote from the highway, has been used as an open septic tank since 1901, without cleaning. The other two sets are provided with screening bars between the grit chambers and the tanks, and the sludge is sluiced away about once a week in open channels and built up with straw and cow manure into compost heaps above the ground level. One of the deposit tanks is close by the highway and is separated from it by an open fence only.

The chief sources of revenue from the farm are milk, green forage and the sale of fattened cows. Cows are bought when fresh in milk, milked for about 15 months, fed for a month or so to complete the fattening begun while they are getting dry, and then sold for killing.

The standard herd is 48 cows, but not so many cows are kept in winter as in summer. For the year 1902-3 an average of 34.4 cows was kept and produced an average of 759.8 Imp., or 912 U. S., gallons of milk each. The preceding year the corresponding figures were 36.6 cows and 764 Imp., or 917 U. S., gallons. The milk is sold to the military hospital and camp.

The dairy house has a cemented floor, apparatus for cooling the milk, a steam jet and a boiling vat for the milk cans. The cowhouses are commodious, with about 1,000 cu. ft. of space per cow. The gutters behind the cows are of concrete, finished with cement mortar, as are also the combined water and feed troughs in front of the cows. The standing room for the cows has its rear part paved with notched brick and its front part covered with rammed chalk, to keep the cows from slipping and to prevent injury to their knees when they lie down or get up. Both the feed trough and the manure gutter are flushed out with water three times daily. The manure is thrown under a shed and covered with straw. The cowhouse walls are of brick and the inside walls and ceilings are whitewashed.

The recently built workmen's cottages are of brick, but some of the earlier ones were of corrugated iron. The cottages are too small for the large families of farm laborers, being modeled after those designed for married soldiers and having only two sleeping rooms. Larger cottages would make it easier to keep the farm laborers permanently.

On walking over a large part of this farm, I saw only one small field which showed evidences of sewage ponding, and presumably this was due to the bad winter which had just passed. No odors were observed, not even at the septic tank. The effluent was clear. It discharges into the Blackwater River and finally into the Thames, and thus the farm comes within the jurisdiction of the Thames Conservancy Board. I saw a number of copies of the results of analyses of samples of effluent taken for the board. The invariable comment, if any, under "remarks," was "not a bad effluent," which seemed to be as far as the board was willing to commit itself.

CHAPTER XIX.

The Great Sewage Farm of Nottingham.

Several men whose opinion I value highly urged me not to fail to visit the Nottingham sewage farm. I say urged, but I needed little urging after having been assured that it was the best-managed sewage farm in England. Father and son together, this farm has been virtually under one management since it was laid out twenty-five years ago. Even then Mr. James Avis had such a reputation that the authorities of Nottingham waited some months for him to finish another engagement in order to secure his services in laying out the farm. When the land was ready Mr. Avis became manager, a post which he held until his death in 1897, when he was the oldest sewage farm manager in England. During his long and active life Mr. Avis was retained by many cities to lay out, or advise in the laying out and management, of sewage farms, and when he died his work was taken up by his son, Mr. Arthur A. Avis,* who had been assistant manager of the Nottingham farm for ten years and who has been manager for the past eight years.

Nottingham has a population of 240,000 and an area of 10,935 acres. It bought the water-works in 1879. The water supply is pumped from deep wells in the new red sandstone. Mr. A. Brown, M. Inst. C. E., is city engineer. Mr. M. Ogle Tarbotton, M. Inst. C. E., was engineer to the sewage farm committee at the time the land was laid out and the pumping station and outfall sewer built.

The sewers of Nottingham are on the combined system. There are 11,850 water closets and 2,334 waste water closets connected with the sewerage system, as compared with 40,550 tub or pail closets and 300 midden privies. The total dry weather flow of sewage is 9,000,000 Imp., or 10,800,000 U. S., gallons, of which 3,600,000 U. S. gallons come to the works by gravity and 7,200,000 U. S. gallons are pumped at Nottingham. The average flow of the sewage from the city to the farm is six miles. Nottingham is on the River Trent, which is navigable here. When the rainfall amounts to 1 in. in twelve hours and the river attains a certain height the pumps are shut down and all the flow of sewage is discharged directly into the river. The two outfall sewers are designed for a combined capacity of 26,000,000 Imp., or

*Stoke Bardolph, near Nottingham, England.

31,200,000 U. S., gallons, and all the sewage arriving at the works is applied to the land.

The total area of the farm is 1,950 acres, of which 1,300 acres has been laid out, and the balance is gradually being prepared for the reception of sewage. The farm has a gravelly subsoil.

The city owned none of the farm at the outset, but has acquired nearly all the original area and bought much more since then. The first transaction, unfortunately, was a lease of 636 acres at a bad bargain. This was in 1878, before Mr. Avis, Sr., was engaged. The lease was for a period of 65 years, at a rental of £5, or $24.30, an acre for land which had previously been under private lease at a little over a fourth of that rate. In 1890 the area of the farm was increased to 907 acres, in 1899 to 1,300 acres, and in 1902 to 1,950 acres. All the added land was bought outright and from time to time portions of the leased land have been bought until all but 173 acres is now owned by the city. Buying up the leased land, including the cancellation of the lease, has cost an average of $583 an acre, and the average cost of the 1,777 acres now owned by the city is $535 per acre. The farm was put in operation in 1880.

About 120 acres of the original area has been provided with 12-in. main drains, 132 ft. c. to c., and 4-in. laterals, 33 ft. c. to c. This land is operated as a filtration area, for use when for any reason irrigation cannot be practiced. The remainder (that is, 1,080 acres) has similar drains; only at twice the distance.

The gross revenue of the farm is £16,000, or $78,000, of which about a seventh is from milk. At the time of my visit (April 22, 1904), there were on the farm 620 cattle, including 92 milch cows; 620 sheep; 320 swine; and 130 horses, including working and breeding animals and young foals. The staple sewage crops are Italian rye grass, mangel-wurzels, ox cabbage, kale and kohlrabi, all of which take large volumes of sewage. For rotation, clovers, market cabbage, wheat, barley, oats, potatoes and swede turnips are raised. The sheep and many cattle are fattened for market. Horses are bred and when old enough they are put to work on the farm, but at five years of age and upwards they are sold to other departments of the city, and also to other customers. Cows are bred for milking and fattening. Yorkshire white pigs are also bred; the best are sold over all parts of the world for breeding purposes and the inferior ones are fattened.

Until 1903 the farm has always paid working expenses and contributed towards the rent, the excess sometimes being 50 shillings, or

$12.15, an acre, but the exceptionally wet season of 1903 caused the revenue to fall below the cost of operation.

To milk the 92 cows requires eight men, and in addition a boy is kept busy weighing the milk. Altogether 110 men, youths and boys are employed on the farm, at a yearly total wage of about £4,000, or $19,400. Boys just out of school, say 13 years of age, are started at 6 shillings, or $1.46, a week and advanced sixpence a week, as they deserve, until they receive full wages. The weekly wage and hours kept by the various classes of men are as follows: Laborers, 17 shillings, or $4.13, from 6 a. m. to 5:30 p. m.; milkers, 19 shillings, or $4.62, from 5 to 6; wagoners, 20 shillings, or $4.86, from 5 to 6, and at 8 o'clock to "supper up" (these men drive and care for the horses used in various classes of farm work). Assuming half an hour for breakfast and an hour for dinner the laborers work 10 hours and the milkers and wagoners 11½ hours a day, not including the time taken to feed the horses at night. The milkers work at something else between milkings. Engineers (i. e., drivers of and steerers of traction engines and drivers of cultivating engines) are paid 25 shillings, or $6.07, a week and work from 6 to 5:30. The various foremen are paid as follows: Of laborers and milkers, 26 shillings, or $6.32; of wagoners, 30 shillings, or $7.29; of enginemen, 40 shillings, or $9.72. All these men, it should be understood, have houses and gardens, rent free, or in lieu thereof receive one shilling, or about 25 cts., a week extra. There are but few outside men.

Obviously a man who operates a farm of 1,950 acres, handles 110 men and boys and looks after 1,700 head of live stock, including 90 milch cows and their products, and at the same time disposes of the sewage of a city of 240,000 people has large responsibilities. I conclude that Mr. Avis is given a pretty free hand in the management of the farm, and that this is essential to success. He is of the opinion that most sewage farm managers do not have a fair chance, being hampered by either medical officers of health or borough surveyors, and that this makes it difficult to get and keep good men for such positions as his.

I had the pleasure of driving over a considerable part of the Nottingham farm (in the rain). Everything seemed to be in remarkably good condition. A main effluent ditch was flowing some 4 ins. deep with what looked like the clearest spring water. The effluent from this farm, in company with that from a number of other farms and from so-called bacterial processes, is being closely studied by the Royal

Commission on Sewage Disposal, and I have reason for believing that some interesting comparative results will be made available within a year or so.

Naturally I could not visit such a sewage farm without speculating on what would happen should an American city undertake such an enterprise. To begin with, a city of 240,000 people would have a dry weather flow of from twice to four times that of Nottingham, and it would have to pay about double the rate of wages for a shorter day's work. Instead of succeeding his father as manager a man would be lucky if he succeeded himself for more than two or three years, although once out he might be reappointed when his political party won another city election. But all these troubles might be as nothing compared with the difficulties encountered in finding "places" for and managing the men sent to him by political party managers. As we know too well in America, but as I have had the greatest difficulty in making British municipal officials see, candidates for positions on American sewage farms would be chosen for quite other reasons than fitness for the work in hand.

As a rule the purely natural conditions in many sections of the United States are far more favorable to sewage farming than they are in England, but nearly all other conditions, and they are many, are against the practice. We have fortunately never been carried away with the glowing claims for profits from sewage farming, although not infrequently they are urged by well-meaning but ill-informed persons. I am pleased to say that the best men I have seen here are not thus deluded. Colonel Jones, as stated in Chapter XIX., charges up the net loss on the Aldershot Farm as "cost of sewage disposal," and Mr. Avis views the subject in the same light. The question naturally arises, why pile up capital account and working expenses to such an enormous extent to reduce the cost of sewage disposal if by other means both charges can be kept at a much lower figure and all the difficulties incident to municipal farming be avoided? This question is far more pertinent in America than in Great Britain. At home I think the answer will continue to be against sewage farming, but in saying so I do not mean to disparage the excellent sewage farms which I have seen in Great Britain nor the ability and character of the men who are managing them.

CHAPTER XX.

The Leicester Sewage Farm and the Proposed Supplementary Works.

The difficulties overcome by Leicester in the disposal of its sewage have been equalled in the case of but few municipalities. The dry weather flow and a part of the storm weather flow of more than 200,000 people is pumped to an elevation of 180 ft. to a sewage farm composed of stiff clay subsoil overlaid with only a foot of topsoil. To secure a statisfactory effluent, double and sometimes triple irrigation is required. With the increase in the volume and the strength of the sewage, the three small detritus or settling tanks have become inadequate and the land is more and more speedily clogged with sludge deposits. By sacrificing crops and sparing no expense for labor, I am told, a satisfactory effluent has been maintained since sewage was first delivered on to the land in 1890; but it was evident a few years ago that supplementary works would soon be necessary. Accordingly, in 1898, an interesting series of experiments was commenced, to learn just what could be accomplished with detritus and septic tanks, both open and closed, and with the first or with both of these combined with either single, double or triple contact beds. Some of the tests were designed to show the efficiency of the so-called complete bacterial processes, but the main object was to ascertain the best preliminary treatment for the relief of the land. Naturally the borough was loath to abandon its immense sewage farm, on which at the close of 1899 £58,847, or about $285,000, had been expended for construction, besides £12,922, or about $60,000, had been paid for force mains, in addition to the large cost of the pumping station.

The necessity of supplementary works was still further increased by the desire of the borough to concentrate its sewage disposal at its main sewage farm, thus enabling it to abandon one small pumping station and one small sewage farm. When the smaller of these two schemes was laid before the Local Government Board in 1899 that body lost little time in declaring the existing settling tank capacity at the main, or Beaumont Leys, sewage farm too small and asking for an increase of 150% in capacity. The minor change, however, was finally sanctioned on the borough's representation that it was considering even more important supplementary works, and with the understanding that tanks would be added in three years, or sooner if de-

manded. This was before the publication of the report on the experimental work, which was dated January, 1900.

The interesting and valuable report in question was made by Mr. E. George Mawbey, M. Inst. C. E., Borough Surveyor, who conducted the tests in behalf of the Sewage Works and Farms Committee of the Borough Council. Mr. Mawbey recommended that additional detritus or settling tanks and new single contact beds should be constructed for the preliminary treatment of the sewage, at an estimated cost of about £85,994, or $418,000. Up to April, 1904, none of the supplementary works had been put under construction, but a large quantity of material had been accumulated for the contact beds.*

Leicester has a population of about 225,000. Its area is 8,586 acres. The water-works are owned by the borough, the entire supply being collected in gathering grounds, stored in impounding reservoirs, filtered and pumped to service reservoirs.

The sewers are mostly on the combined plan, and with the exception of about 376 all the houses are provided with water closets. No less than 6,512 pails and privies have been abolished during the last three years. Of the three sewage farms now in use, the two small ones receive little trade waste, but the main, or Beaumont Leys, farm receives a large volume of trade wastes, consisting chiefly of wool scourings and dye washings.

The Beaumont Leys sewage farm now comprises 1,699.5 acres, of which 1,355 are available for receiving sewage. The Belgrave farm has 37¼ acres, of which 35 receive sewage. The Knighton farm has 23 acres, of which 22 receive sewage.

Sewage was first pumped to Beaumont Leys on Sept. 29, 1890. The Belgrave farm was put in use in 1883, and the Knighton farm in 1887.

Prior to the establishment of the Beaumont Leys farm the sewage now sent there was treated by lime and chemical precipitation. For 35 years the effluent gravitated directly into the River Soar. This plant was kept in operation until April, 1893, when sufficient land had been made ready to receive the sewage without previous treatment. The sewage of the other parts of the borough was not treated prior to the inauguration of the Belgrave and Knighton farms. Previous to the abolition of the Knighton pumping station all the sewage was

*Mr. Mawbey writes me in July, 1904, that a contract has been let for the effluent pumping station and that the bacteria beds will be commenced during the present year.

pumped, the lift at this farm being about 50 ft. and at Belgrave 21 ft., while the main farm, as already stated, requires a total lift of 180 ft. The Knighton pumping station having been abolished, the bulk of the sewage has been diverted to Beaumont Leys, and a new pumping station is being erected at Belgrave to pump the dry weather flow, and up to three times that volume received at Belgrave, to the Beaumont Leys farm. In addition, a second three times the dry weather flow will be treated on storm water beds now being constructed, and the balance, namely the combined flow after six times has been treated, either at Beaumont Leys or on the storm water filters, will overflow into the River Soar.

One hundred acres of the Beaumont Leys farm was purchased for £13,000, or $63,000, when the scheme was first adopted, the remainder being rented from private owners under a lease terminating in 1916. In 1902, however, the municipal corporation purchased a further area of 1,270 acres of this land at a cost of £173,990, or $845,000. This course was recommended by Mr. Mawbey in his report on the supplementary works.

Of the 1,355 acres here receiving sewage, 902 acres are described as old pasture and 453 as arable land. Notwithstanding the fact that this land is a stiff clay, it began to receive sewage in 1890 at the rate of more than 100 persons per acre, which rate has increased until now it is about 150 persons per acre. For some three years part of the sewage delivered on to the land had chemical treatment, but since 1893 it has had the benefit of a decreasingly brief period of sedimentation, as already noted.

The sewage of the greater part of Leicester, or of 210,000 out of a total population of 225,000, is delivered by gravity to the Beaumont Leys pumping station. The daily dry weather flow is about 8,000,000 Imp., or 9,600,000 U. S., gallons. Just how much of the storm flow is delivered to the sewage farm I did not learn. All the sewage is roughly screened at the end of the outfall. Such of it as passes the overflow weir goes through a culvert 8 ft. in diameter and three miles long, discharging into the River Soar. There is a fixed gage at the overflow weir, from which frequent readings are taken when the combined sewage and storm water is passing over the weir. The volume of sewage passing to the pumps is indicated by automatic recording gages and also by the pump counters.

At the sewage farm the force mains terminate in two bellmouths, from which the sewage flows into the three detritus, or settling, tanks,

each about 60 ft. x 90 ft. x 6 ft., with a combined holding capacity of 600,000 Imp., or 720,000 U. S., gallons. Two of the tanks were covered with scum at the time of my visit. About once in three weeks the sludge is pumped from the tanks to uncropped land, on which it is spread in thin layers and subsequently plowed in.

The tank effluent flows through main carriers of brick, and thence it is distributed through subsidiary pipe carriers on to the land. From 300 to 400 acres of land are required daily for the reception of the sewage. The sewage is first applied to uncropped land, and a large part of it is collected in intercepting grips at the lowest part of the field, after having passed over the surface only. This is next applied to the surface of pasture land, and if, as judged by visual inspection, it is not sufficiently purified thereby, it is applied to a third area.

Before the borough leased the land it was partially drained with tiles. Some of the sewage effluent, it was found, passed away through these drains in bad condition. To remedy this Mr. Mawbey made separate provision for dealing with the drain effluent from each field. This was effected by constructing master drains to intercept the flow from the laterals. These drains lead to chambers, each of which is provided with two valves. If the effluent is sufficiently clear it is allowed to pass on to the water course, but if not it is sent to a lower field for a second treatment.

The only crop to which sewage is applied is Italian rye grass.

About 1,000 cattle are pastured in summer, but they are all bullocks for fattening. For four or five months in winter the cattle are kept in sheds having roofs covered parallel to the rafters with 1 x 6-in. boards, laid so that their edges just touch. Subsequently the boards shrink so as to leave spaces about 1/4 to 3/8-in. between them. Near each weather edge of these boards there is a small groove to assist the drainage to the eaves. There is but little snow at Leicester.

On land which is being given long rests from sewage mangel-wurzels, swede turnips and oats are raised.

I visited this farm on a cool day following rainy weather. There was no odor. Some plowed land which had been receiving sewage was pretty well covered with sludge. The surface effluent from the first application of sewage to the land was fairly clear. The first drain effluent was less in quantity and clearer than the corresponding

surface effluent, but showed a gray fungus growth. The final effluent was clear, showed no fungus, but plenty of green growth. I was indebted to Mr. Mawbey for an opportunity to visit the sewage farm, and for sending Mr. Willis Wigg, his chief assistant in the sewerage and sewage disposal departments, to explain its working to me.

A few words may well be said about the experiments already mentioned. They were begun on Aug. 31, 1898, and continued for about 13½ months. The plant was located at the Beaumont Leys farm, and included a detritus tank 15 x 30 ft. in plan at the sewage level and 7 ft. deep at the center, with a holding capacity of 17,000 Imp., or 22,000 U. S., gallons; a settling, or septic, tank 30 x 130 ft. in plan at the sewage level, with average depths of 6 ft. at the inlet and 4¼ ft. at the outlet end, with a sludge channel below, and a holding capacity of 126,000 Imp., or 151,000 U. S., gallons; about 4,400 sq. ft. of "clarifying bacteria beds" 4½ ft. deep, and 1,350 sq. ft. of second and third contact beds 3 ft. in depth. All the beds save one were filled with destructor clinker, but in the first contact beds two 6-in. layers, 1 ft. apart, of flattened tins from the local refuse destructors were placed. One of the fine contact beds was composed of layers of destructor clinker and of burnt clay ballast. Both the detritus and the septic tanks were open at first, but subsequently they were closed. Throughout the experiments all the sewage was passed through the small detritus tank. The effluent from this was subjected to a variety of treatments and combinations of treatment. Some of the tests were of brief duration, as must have been the case when all were conducted within 13½ months, and in other respects it seems questionable whether the conditions were such as to give all the methods tested a relatively fair trial. It should be remembered, however, that the main object of the experiments was to indicate the best mode of preliminary treatment for the relief of the existing sewage farm. The conclusion was that sufficient relief could best be obtained by increasing the capacity of the present settling tanks from 600,000 Imp., or 720,000 U. S., gallons to 1,400,000 Imp., or 1,680,000 U. S., gallons, or about one-eighth the dry weather flow in 1915, and constructing twelve acres of single contact beds. The sludge from the settling tanks would gravitate to a reservoir, from which it would be pumped through 6-in. cast iron mains to lagoons on different parts of the farm. The effluent from the contact beds would also have to be pumped, but this would require only two 40-in.

cast iron mains about 400 ft. long, with a working head of about 15 ft.

I cannot close what I have to say about Leicester without calling attention to it as a remarkable example of what can be accomplished under conditions most adverse to sewage farming when the work is entrusted to a capable engineer. Certainly at the Leicester sewage farm, if anywhere, the forces of nature have been dircted in the service of man.

PART IV.

Chemical Precipitation Works.

CHAPTER XXI.

Chemical Precipitation and the Proposed Septic Tanks and Contact Beds at London.

Some 235,000,000 Imp., or 280,000,000 U. S., gallons of sewage a day are treated chemically at the Barking and Crossness outfalls of the London main sewers and 7,200 long tons per day of resulting sludge are sent a distance of fifty miles to sea by means of a fleet of six large steamers. Capital charges and operating expenses included, precipitation and sludge disposal cost about £182,000, or nearly $900,000, a year. As a result of experiments extending over a period of ten years or more, it has been decided that it would be practicable to substitute detritus and septic tanks for chemical precipitation and to treat the septic effluent in single contact beds composed of coke. The diminished quantity of sludge resulting from this process would continue to be sent to sea.

The trunk sewers and the sewage works of London are under the control of the London County Council. The population of the County of London was 4,536,541 in 1901, distributed over an area of 118 square miles, but portions of the sewage of the outside population of several districts, located on some twenty-seven miles of additional territory, are received into the main drainage system. The water supply of London is derived mostly from the Thames and Lea, the remainder coming from wells in the chalk. All the water is pumped, and all that taken from the mains is filtered. A large part of the sewage is also pumped.

Up to about 1815 such sewers as existed in what now constitutes the County of London received storm water only, it being a penal offense to discharge organic wastes into them. Later it became permissive, and in 1847 it was made compulsory to abolish cesspools and privies and connect water closets with the sewers.

In 1847 a Metropolitan Commission of Sewers, appointed by the National Government, superseded eight local commissions, but ac-

complished practically nothing toward stopping the pollution of the Thames by the many sewer outlets within the city limits. In 1855 the Metropolitan Board of Works, composed of representatives from 39 districts, was appointed, and subsequently, with Sir Joseph W. Bazalgette as engineer, it constructed intercepting sewers on either side of the Thames, with outlets, some fourteen miles below London Bridge, at Barking on the north and Crossness on the south side of the river. The Crossness outfall sewer was completed in 1862, and the three sewers at Barking were completed in 1863 and 1864. There was also completed in 1864 a covered terminal reservoir at Barking having a capacity of 35,000,000 Imp., or 42,000,000 U. S., gallons, and late in 1864 or early in 1865 one was also completed at Crossness with a capacity of 25,000,000 Imp., or 30,000,000 U. S., gallons. These reservoirs were designed, and until their capacity was exceeded by the volume of sewage they were used, to store the sewage for discharge on the outgoing tide. Various pumping stations were also built from time to time, all of the sewage at Crossness, but none of that at Barking, being pumped; besides, there were pumping stations to lift the sewage of certain districts into the main sewers. It should also be noted that storm overflows were provided for the relief of the main sewers, and that these are still in use; in fact, for all London an average of only ¼-in. of rainfall per 24 hours reaches the main outfalls.

Complaints of nuisance from the discharge of sewage at the new outfalls having arisen, a Royal Commission to look into the matter was appointed in 1882. After a long inquiry it recommended that the sewage be treated before its discharge into the river. The Metropolitan Board of Works, after experiments had been conducted by Mr. W. J. Dibdin, Chemist to the Board, decided to adopt chemical precipitation, with lime and protosulphate of iron as agents, and in January, 1887, contracts for the necessary changes and additions at Barking were made. In 1888 a similar contract was let for works at Crossness. The Barking precipitation works were put in operation in July and August, 1889, and the Crossness on June 2, 1892.

The London County Council succeeded the Metropolitan Board of Works in March, 1889, and Sir J. W. Bazalgette was followed as chief engineer by Mr. W. J. Gordon, who lived but a few months. From 1890 to 1901 Sir Alexander Binnie was chief engineer to the County Council, and he was succeeded by Mr. Maurice Fitzmaurice,

M. Inst. C. E., the present incumbent. Since 1893 Mr. J. E. Worth, M. Inst. C. E., has been engineer of the Northern District and Barking works. The present engineer for the Southern District and Crossness works is Mr. R. M. Gloyne. In 1897 Dr. Frank Clowes succeeded Mr. Dibdin as chemist to the London County Council. Under him Mr. E. Brooke Pike is chemist in charge at the Barking works, and Mr. J. W. H. Biggs holds the same office at Crossness. I am indebted to Dr. Clowes for a visit to the Barking and Crossness works, and to Messrs. Pike and Biggs for courtesies shown me there. I am also indebted to Mr. Worth for important aid rendered me in gathering information regarding the sewage works of London.*

Sir J. W. Bazalgette's intercepting sewers, with discharge of crude sewage into the Thames, raised a storm of protest, both from those who thought the interests of the river and vicinity demanded purification, and from others, who urged that it was a shame to waste such vast quantities of rich fertilizing material. No end of schemes for sewage treatment were presented from 1855 to 1890. Among those tried, at considerable expense, were the A. B. C. process of the Native Guano Co. and the Webster process of electrical treatment. Many thousand pounds sterling were also sunk in a scheme to utilize the sewage on marsh lands, the net result of which, aside from the loss of good money, is a large brick sewer, now exhibited to visitors at Barking on account of its fine echo-producing qualities.†

It is clearly shown in Mr. Dibdin's paper of 1887 (see footnote) that his preference at that date was for bacterial rather than chem-

*The various Engineers named may be addressed, Care of the London County Council, Springs Gardens, London, S. W., and the Chemist, at 40 Craven St., London, S. W.

†Some idea of the controversies over proposals to deal with the London Sewage may be gained from the discussion on "Sewage Sludge and Its Disposal," by W. J. Dibdin, and "Filter Presses for the Treatment of Sewage Sludge," by the late W. Santo Crimp, Proc. Inst. C. E., Vol. LXXXVIII. (1886-7) Part II. Later discussions followed: "The Main Drainage of London," by J. E. Worth and Santo Crimp, and "The Purification of the Thames," by W. J. Dibdin (Proc. Inst. C. E., Vol. CXXIX., 1896-7), Part III. The first of these two papers included a historical review of the London main drainage system, and a description of the chemical precipitation works built from 1887 to 1892, together with descriptions of new pumping stations. A more detailed description of the original main drainage works, by Mr. Bazalgette, may be found in Proc. Inst. C. E., Vol. XXIV. (1864-5.)

ical agents in the treatment of sewage. At that time, however, little was known regarding the practical adaptation of bacteria to sewage treatment beyond their use in sewage farming, a process deemed wholly impracticable for London. As shown in Mr. Dibdin's paper, he had learned, by means of experiments, that relatively small quantities of lime and protosulphate of iron (4 grains and 1 grain per Imperial gallon, respectively) were very effective in expediting the sedimentation of London sewage. Those agents were adopted, and since 1892 they have been used (substantially in those proportionate amounts), with great benefit to the river. But that chemical precipitation was not regarded as a permanent, or at least as a sufficient, method of treating the sewage of London is shown by the fact that in 1892, a month before the second precipitation works were put in operation, Mr. Dibdin began experiments at Barking on the so-called bacterial treatment of sewage. These experiments were ordered by a committee of the County Council in March, 1891, shortly after the appearance of the earliest reports on the experiments of the Massachusetts State Board of Health. The chief object of the early experiments was to determine the effect of bacterial treatment on chemically treated sewage. In 1898 the experiments at Barking were extended, and experiments were also inaugurated at Crossness, with the view of determining the best depths for contact beds, the possibility of treating crude sewage in such beds, and of substituting either plain settled or else septic sewage for effluent from chemical precipitation tanks. It is impracticable to review the experiments in detail.* It may be said, however, that after trying burnt clay, coke, sand and a proprietary material (which, as a guess, I should say was polarite), pan breeze, a harder burnt material than ordinary coke, was considered to be best suited for the purpose. The proximity of a large gas works, affording this pan breeze at a low figure, doubtless contributed toward the choice of that material. The one acre coke-bed was originally about 3 ft. deep, and was subsequently made 6 ft. deep. Tanks filled with this pan breeze, of vary-

*A valuable series of reports on these experiments has been published by the London County Council. Most fortunately for all interested in the subject, these reports, which are out of print, have been somewhat condensed and combined in a single volume: "The Experimental Bacterial Treatment of London Sewage." By Prof. Frank Clowes and A. C. Houston, London: P. S. King & Co. (1904).

ing depths up to 12 ft., were also employed. The main conclusions drawn from the experiments were as follows:

(1) That by suitable continuous undisturbed sedimentation the raw sewage is deprived of matter which would choke the coke-bed, and the sludge which settles out is reduced in amount by bacterial action to a very considerable extent. This reduction might undoubtedly be increased by the preliminary removal of road detritus.

(2) That the coke-beds, after they have developed their full purifying power by use, have an average sewage capacity of about 30% of the whole space which has been filled with coke.

(3) That the sewage capacity of the coke-bed, when the bed is fed with settled sewage, fluctuates slightly, but undergoes no permanent reduction. The bed does not choke, and its purifying power undergoes steady improvement for some time.

(4) That coke of suitable quality does not disintegrate during use.

(5) That the "bacterial effluent" of settled sewage from the coke-bed does not undergo offensive putrefaction at all, even in summer heat, and can never become offensive. That this effluent satisfactorily supports the respiration of fish.

(6) That the use of chemicals is quite unnecessary under any circumstances when the above method of treatment is adopted.

Applying these conclusions to the London sewage works, it appears that chemical precipitation might be given up, and the sewage "satisfactorily treated" by:

(1) Screening out the coarser matters and depositing the heavier, suspended mineral matters in detritus chambers, the detritus to be placed on waste land.

(2) Utilizing the covered channels now employed for chemical precipitation as septic tanks. "It might be necessary at long intervals," the report states, "to remove some" sludge from the tanks, but the quantity produced would be "much less" than that now handled as a result of chemical treatment. This change would save all the expense for chemicals and part of the cost of sludge disposal at sea.

(3) The effluent from the septic tanks, which "would contain a minimum quantity of suspended matter," must be aerated to remove sulphuretted hydrogen. For this, perforated trays are suggested. Next, the effluent would be applied to coke beds, which could be filled four times a day, with 2½ hours of rest between emptying and filling. The effluent from such beds would then be sufficiently pure for admission into the lower Thames. It would never lead to offensive smell or de-aeration of the river water, and would readily support fish life.

It was found that sewage could be dealt with at the rate of 4,356,000 gallons (5,225,000 U. S. gallons) per acre in 24 hours in a coke-bed 12 ft. deep.

It is suggested, however, that although the experiments guarantee satisfactory results on a large scale, they were conducted with a unit much smaller than would be used for testing the whole sewage of London, and that it would, therefore, "be well to commence the treatment on the large scale by constructing and working with several larger beds before proceeding to construct the whole installation."

In considering the enormous rate of application per acre of contact beds given in the report, it should be remembered that it involves contact beds 12 ft. deep, and that the final effluent would be discharged into a large volume of tidal water.

A section of the report worthy of careful consideration is that prepared by Dr. A. C. Houston on the bacterial phases of the treatment of sewage in contact beds. It must suffice for this place to say that, as a result of a long and apparently careful series of investigations, Dr. Houston concludes that the bacterial contents of sewage from contact beds are nearly as high, and sometimes higher, than those of the applied sewage, and that so far as pathogenic germs are concerned there is little to choose between the applied sewage and the effluent.

It has already been stated that the total quantity of sewage being treated at Barking and Crossness is about 280,000,000 U. S. gallons a day. Of this about 136,200,000 Imp., or 163,000,000 U. S., gallons is treated at Barking, and 97,000,000 Imp., or 116,400,000 U. S., gallons at Crossness.

The sewage comes to each works well broken up by its flow of some 15 to 20 miles, besides which, a portion of the sewage coming to Barking has been pumped twice, and all the sewage at Crossness is pumped once, while a portion of that at Crossness has been pumped before it reaches the works. At Crossness all the sewage is screened before it is pumped. At Barking, at the present time, the sludge only is screened from the settling channels.

There are 13 brick covered precipitation tanks, or channels, at Barking, ranging from 860 to 1,210 ft. in length, and having a width of 30 ft., an average working depth of 8 ft., and a combined holding capacity of a little more than 20,000,000 Imp., or 25,000,000 U. S., gallons. The effluent from the channels passes into the old 42,-

000,000 U. S. gallon tidal reservoir, and thence through nine openings into the river. The tanks are operated separately, on the continuous flow plan.* There are also twelve sludge settling tanks, each 20 x 140 ft. x 13 ft. effective depth. Since 1894 three elevated steel sludge tanks have been built at Barking. Each tank has a capacity of 1,000 long tons, or one shipload. Normally, the sludge is pumped to the boats, but the tanks are kept full for the quick loading of boats that come in near nightfall and for loading on Monday morning.

At Crossness the old tidal reservoir was converted into four covered precipitation tanks, each 560 ft. long and 128 ft. wide, and two new covered tanks were built, each 558 ft. long and 99 ft. wide. The combined holding capacity of these six tanks is about 21,700,000 Imp., or 26,000,000 U. S., gallons. There are also eight sludge settling tanks, 130 x 22 ft., with a working depth of 15 ft.

Six sludge ships were put in service from 1887 to 1895, inclusive. They are approximately 230 ft. long, 38 ft. broad, 14 ft. deep, and on trial developed from 950 to 1,250-HP. each. The two earlier boats are loaded through hatchways and the four later ones are loaded through a central hopper, from which inlets controlled by valves lead to the four sludge compartments, formed by a longitudinal and a cross bulkhead. The load of 1,000 long tons can be discharged through eight valves in six minutes, but as a rule each sludge load is distributed over a course taking an hour, at a speed of ten knots. As a rule, five boats are in service at a time, and one is being overhauled.

In July, 1891, a two-cell refuse destructor was installed at Barking to burn the screenings from the sewage. Small coal was used for fuel to assist in the burning of these wet screenings. By 1897 the destructor was unequal to the increased volume of screenings, and it is now disused. The screenings are barged away and put on land for agricultural purposes.

In 1902, the last year for which figures are available, a total of 85,000,000,000 Imp., or 102,000,000,000 U. S., gallons of sewage was

*The works at Barking were first operated on the intermittent plan, and the tank effluent was drawn off by telescopic weirs. A change to fixed weirs and continuous flow was made in 1891, and as a result the quantity of sludge produced immediately increased from 7,000 to 23,000 long tons per week. The design of the Crossness works, then under construction, was thereupon changed to fixed weirs and continuous operation. The telescopic weirs are used at Barking (and Crossness) for drawing off the supernatant liquid prior to removing sludge from the tanks.

treated at the two works, and 2,607,000 long tons of sludge, containing a little over 92% of moisture, were produced and sent to sea.

The average cost of treating the sewage and conveying the sludge to sea was £2 2s. 10.2d. per 1,000,000 Imp. gallons, or about $8.67 per 1,000,000 U. S. gallons. A total of 21,741.34 long tons of lime and 5,412.6 tons of protosulphate of iron was used during the year, being an average of 4.01 grains of lime and 1.0 grain of iron per Imperial gallon (or 3.34 and 0.83, respectively, per U. S. gallon). At the Barking works, where the sewage is much the stronger of the two, 4.61 grains of lime per Imperial gallon were used, as compared with 3.17 at Crossness, but the difference between the iron sulphate used at the works was much less marked.

A practice instituted by Mr. Dibdin and continued by Dr. Clowes was to take 9 to 12 weekly samples of water from the Thames at various points between Charing Cross Bridge and the two outfalls, with occasional samples further down the river. These samples are examined on a boat, by means of a portable laboratory, to determine the quantities of free oxygen and of sodium chloride (chlorine) in the water. At the same time records are made of the temperature, weather, and the state of the tide. By this means much valuable information regarding the condition of the river is being obtained for future use. The samples are collected and tested alternate weeks by Messrs. Pike and Biggs, the chemists at the Barking and Crossness works, respectively. The London County Council's steamer "Beatrice" is at the disposal of Dr. Clowes and his assistants every Tuesday for this work, and it was on one of these trips that I visited the works at the two outfalls. During the visit I also saw the one acre coke bed at Barking, also the small experimental beds at Crossness, where work, however, had been discontinued.

I saw a fully equipped chemical laboratory at both Barking and Crossness, and was told that daily analyses are made of samples collected at frequent intervals. Three samples are also taken from every cargo of lime; one is given to the contractor who supplies the lime, one is reserved for a referee, and one is analyzed at the sewage works. The lime is paid for according to the amount of pure lime (Ca O) which it contains in excess of 95%. Lime below 85% is rejected.

In conclusion, it may be said that the engineering department of the London County Council is working on plans and estimates for

new sewage works, in accordance with the general conclusions of the chemist, but that owing partly to the large sums now being expended on improvements to the main sewers and partly to a desire to await the final report of the Royal Commission on Sewage Disposal it will probably be some years before a change from the present system of sewage treatment is made.

CHAPTER XXII.

Chemical Precipitation at Glasgow.

At a time when other cities are rivalling each other in their haste to abandon chemical precipitation Glasgow is installing immense works of that class to serve itself and its neighbors. In May, 1894, its Dalmarnock works were opened, which are now treating a dry weather flow of 16,000,000 Imp., or 19,200,000 U. S., gallons, and will ultimately treat 20,000,000 Imp., or 24,000,000 U. S., gallons a day. A plant which will eventually treat nearly 49,000,000 Imp., or 58,800,000 U. S., gallons of dry weather sewage a day has been completed at Dalmuir, seven miles below Glasgow. A third plant, for an ultimate dry weather flow of 48,000,000 Imp., or 57,600,000 U. S., gallons, will soon be built at Shieldhall, one mile below Glasgow and on the opposite side of the Clyde from the other two plants. The combined dry weather flow of the three works will be 117,000,000 Imp., or 140,400,000 U. S., gallons. The Dalmarnock works were designed before the tide set against chemical precipitation, but the city did not commit itself to that process for the two larger districts until it had made exhaustive enquiry and tested septic tanks and double contact beds on a large scale.

Glasgow alone has a population of about 780,000 and an area of 12,688 acres, or nearly 20 square miles. The combined population of the outlying districts joined with it for sewage disposal is relatively small, but city and suburbs together extend along both banks of the Clyde for about 15 miles and have an area of 39 square miles. Probably this area will be increased by the admission of other small communities, with some of which negotiations are already in progress.

Glasgow is a water-closet town. It has combined sewers, designed to carry, for the whole area of the city, 1¼ in. of rainfall per day. This is the proportion that will be treated at the several works. All the sewage treated at Dalmarnock is pumped, as will be nearly half of that at Dalmuir and more than half of that at Shieldhall.

The sewage at Dalmarnock is largely trade refuse, and is subject to frequent variations in character during the day, the suspended matters ranging from 21 to 980 grains per Imp. gallon, or 30 to 1,400 parts per 100,000. At the other works the character of the sewage will be much simpler, and the effluent will also be diluted by a far greater volume of river water. The Clyde seven miles above the Dalmarnock works, and well above tidal influence, has an average flow of 432,000,000 Imp., or 518,000,000 U. S., gallons a day, or more than 20 times the ultimate dry weather flow to the Dalmarnock works, the chemically treated product of which will be still further diluted by the increased flow due to tidal action. At the lower works the tidal effect will be still greater, it being estimated that the dry weather sewage flow of 49,000,000 Imp., or 58,800,000 U. S., gallons treated at the Dalmuir works will be diluted at Dalmuir by 3,000,000,000 Imp., or 3,600,000,000 U. S., gallons of water, making a dilution of about 70 to 1 for the Dalmuir effluent only, and of about 27 to 1 for all the effluent discharged into the river at the several works. Moreover, as will be shown later, the Dalmuir and Shieldhall tanks are expected to give better effluents than is given by those constructed some ten years ago at Dalmarnock.

I spent a day (April 18, 1904) visiting the two precipitation works, several sewage pumping stations and two refuse destructors at Glasgow. I first saw Mr. A. B. McDonald, M. Inst. C. E., City Engineer of Glasgow, who kindly arranged all the details of my visit to the various works and delegated Mr. D. McInness, one of his assistants, to be my guide for the day.

Mr. McDonald expressed himself as not only strongly confident of the wisdom of the city in adhering to chemical precipitation, but as doubtful of the so-called bacterial processes, particularly as regards their expense.*

I shall not attempt to describe the Glasgow sewage works as I saw them except in bare outline, noting a few of the details that I

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*It may be remembered by some that at the International Engineering Congress, held in Glasgow in 1901, Mr. McDonald presented a paper on "The Disposal of Sewage," in which he outlined the sewage works as then built and proposed, and described the tests of septic tanks and contact beds made at Glasgow in 1900 and 1901. Some of my information is drawn from that paper and some from a pamphlet prepared by Mr. McDonald, in September, 1903, for the information of city officials. The late W. Santo Crimp was consulting engineer to the sewage committee when the adoption of septic tanks and bacteria beds was under consideration and joined with Mr. McDonald in reporting against them.

consider of most interest. Before doing that, however, I will give a very brief description of the tests of septic tanks and contact beds made at Dalmarnock in 1900-'01.

A precipitation tank with a holding capacity of 200,000 Imp., or 240,000 U. S., gallons was used as a septic tank, and two other precipitation tanks, having areas of very nearly 400 sq. yds. each, were utilized as double contact beds. The beds were 3¼ ft. deep and were composed of "engine ashes," graded in layers of different sizes, ¾ to ¼-in. from the bottom upwards for the primary, and ½ to ⅛-in. for the secondary beds. The chemical results obtained were satisfactory, double filtration effecting a purification of 95%, but the loss of the beds in capacity was considered high. It was estimated that 75 acres of septic tanks and contact beds "would be absolutely needed at Dalmarnock "for an operation that is satisfactorily carried on just now in the space of 5½ acres," while at Dalmuir 164 acres would likewise be required to do work which "will be satisfactorily accomplished" on 23 acres by means of the proposed chemical precipitation works.*

It should be borne in mind that besides having a large volume of water to dilute its sewage effluent, thus lessening the need for a high degree of purity in the latter, most of the Glasgow sludge is to be disposed of at sea.

The Dalmarnock precipitation works were designed by the late Mr. G. V. Alsing. When put in operation in 1894 the tanks were worked on the intermittent plan and the effluent was passed through small coke filters. The latter, it is said, proved to be detrimental to the sewage, and were subsequently abandoned. The tanks were also enlarged and changed by Mr. McDonald so as to operate on the continuous flow plan.

At the present time lime and sulphate of alumina are used as precipitants. The sewage passes through a catch pit or detritus tank, provided with screens and bucket elevator dredges. There are

*In response to the question, "Were not these comparisons based on a higher degree of purification by the septic tanks and contact beds than is or can be attained by precipitation?" Mr. McDonald replied, by letter, "These comparisons are based on the requirements exacted by the Local Government Board in English towns and districts." It will be seen that this does not answer the specific point raised. As I understood it, the Local Government Board has no jurisdiction in Glasgow, and if it had it seems unlikely that it would insist on high requirements for septic tanks and contact beds and then permit as an alternative chemical precipitation with no subsequent treatment of the effluent.

four precipitation tanks, each 470 ft. x 59 ft. in plan, with an average working depth of 8 ft.

The effluent is discharged into a wide channel, in a thin sheet, and thence falls into a narrower channel. It was remarkably clear at the time of my visit, containing no visible suspended matter. It is stated that besides removing all the suspended matter the process effects 30% of purification as indicated by oxygen absorbed in four hours at 27°C. In place of floating arms for drawing down the sewage to gain access to the sludge Mr. Thos. Melvin, Manager of the works, has devised and installed an invention of his own which may best be described as horizontal slot shutters or a series of iron stop boards mounted on a chain and operated by a windlass. These can be raised one by one, thus letting out the liquid gradually.

The tank sludge is dosed with lime and pressed. Some of it is sold as cake sludge to farmers and some is passed through a Cummer (American) dryer, screened and ground to powder and sold under the name of "Globe Fertilizer." Some of the latter is shipped in bulk and some is bagged before shipment; some is applied directly to land and some is enriched with other fertilizing materials. I was told that the farmers in the vicinity seem to prefer the sludge cake to the powdered sludge, but where sent to a distance the saving in freight due to the reduced weight of the powdered article is advantageous. Some of the sludge cake is sent to the city farm.

The most notable feature of the new chemical precipitation works at Dalmuir, it seems to me, is the great length of the tanks, which is 750 ft., for a width of 50 ft. The sewage, after passing through a V-shaped catch pit, where it is agitated by a travelling dredge, and after being dosed with lime and proto-salt of iron, will be admitted to the six tanks through rectangular openings near the bottom of each end, in front of which are brick baffle piers about 32 ins. high. The liquid will be drawn from the tanks, before sludge is removed, by means of iron lift shutters, or stop gates, like those at Dalmarnock. The sludge will be pumped to two elevated tanks, composed of flanged and bolted cast iron plates, supported on girders resting on brick piers. Each tank is 35 x 150 ft. x 6 ft. depth of sludge, and has a capacity of 1,500 tons. A 1,000-ton sludge boat is being built to convey this material to sea. The engineer for the mechanical apparatus and for the buildings at Dalmuir is Mr. David Hume Morton, M. Inst. C. E., M. Inst. M. E., of 130 Bath St., Glasgow.

CHAPTER XXIII.

Chemical Precipitation and Divers Experimental Installations at Leeds.

Leeds is temporarily in an embarrassing position. After outgrowing the capacity of its chemical precipitation works it began a splendid series of experiments on various so-called bacterial methods of sewage treatment and published several valuable reports on the results of its investigations. The last of these reports was dated July, 1900, and indicated that the sewage of Leeds could be satisfactorily dealt with on continuous percolating filters of coarse material receiving either septic tank effluent or crude sewage. Certain details of construction and operation remained to be settled, and the experiments have been extended in scope and continued up to the present time. In 1900 the city bought 1,890 acres of land some distance down the river from the present works, knowing that whatever method should be adopted a large area would be required for the treatment of the sewage and storm water of so large a city. In 1901 application was made to Parliament for a loan to be used in developing the land just mentioned, but the bill failed. The failure, it is said, was partly due to opposition caused by the necessity of constructing an outfall sewer through private property to the land in question and partly due to objections to the use of the land for such a purpose. It is also said that the experimental results with the so-called bacterial methods, as shown in the published reports, were used as arguments against the necessity of developing a large area for land treatment. It is expected that a second appeal to Parliament will be made during the latter part of 1904. Meanwhile the Leeds experiments are being continued, but no special reports on them have been issued since 1900.

Leeds has a population of some 444,000 and an area of 21,572 acres. The water-works are owned by the city. Mr. T. Hewson, M. Inst. C. E., is city engineer and Mr. T. Hewson, Jr., Assoc. M. Inst. C. E., is deputy city engineer. Since October, 1898, Mr. W. H. Harrison has been chemist to the sewage works committee and has superintended both the chemical precipitation works and the experiments on sewage treatment.

All the sewers at Leeds are of the combined type, but the main sewer is sufficient to carry only 0.05-in. of rainfall per hour, and no

more than 60,000,000 Imp., or 72,000,000 U. S., gallons of sewage and storm flow can reach the works. The greater part of the population is provided with water closets, either single or trough, and the remaining privies are being abolished. Water closets are compulsory in new buildings. The normal dry weather flow of sewage in 1900 averaged some 15,800,000 Imp., or 19,000,000 U. S., gallons a day, and was said to be the same early in 1904.

A sewerage system was built in 1850-5, with a single outfall to the River Aire. Complaints of nuisance soon arose, and in 1867 estimates were secured for an outfall sewer 27 miles long and a sewage farm. From 1870 to 1874 various experimental systems of sewage treatment were tried, the chief of which was the A. B. C. (alum, blood and clay). All were abandoned, and in 1874 chemical precipitation works, with lime as an agent, were put in operation. Those works continued in service without change or extension until March, 1897, when new tanks were added. These tanks were considered as provisional, and resulted, in part, from the pressure brought to bear by the West Riding Rivers Board for a more satisfactory treatment of the sewage.

The sewage at the works is pumped, the average lift being 12 ft. Some of the precipitation tanks having been converted into septic tanks and others into filter beds, and the capacity of the works now being far from sufficient for the sewage flow, no attempt will be made to describe the precipitation works. It is interesting to note, however, that sludge presses have never been used and that the new tanks provided in 1897 could not be fully utilized because the increased output of sludge was more than could be drained and dried in the lagoons used for that purpose. The process required 6 to 12 months, after which, it was said in 1900, farmers were found willing to take away the sludge, provided it was loaded into their wagons, at the works, free of cost. In wet weather, obviously, the sludge dried out less rapidly and the farmers were less likely to call for it, so that storage space sometimes became a serious question. It should be added that the new precipitation tanks, besides increasing the volume of sludge, decreased the lagoon and storage area; and that disposal at sea was impracticable on account of the distance and the small size of the boats on the Leeds Navigation.

Besides the works already outlined an irrigation area of 60 acres was laid out in 1900 to treat the sewage from an estimated population of 4,500 not tributary to the main outfall.

It is interesting to note, as leading up to a brief account of the Leeds experiments, that in 1894 a deputation visited sewage works in the vicinity of Leeds and concluded that the best process of sewage treatment was broad irrigation. For this, however, Leeds would require 4,000 acres of land, which was more than was available near the city. Broad irrigation, supplementary to the existing precipitation works, would require only 400 or 500 acres, but even that amount of land could not be had near by at the time, and the scheme presented no solution of the already serious sludge problem. At the close of 1896 attention was called to the contact beds recently installed at Sutton, Surrey, and at the Barking outfall of the London sewerage system. In July, 1897, Mr. W. J. Dibdin, who had introduced the contact beds mentioned, was called in as an expert chemist to advise whether the trade refuse, including tannery wastes and iron liquor from chemical works, would be inimical to contact beds. Following Mr. Dibdin's advice, the Leeds experiments were begun in October, 1897, two precipitation tanks having been converted into contact beds. These beds were subsequently followed by other beds and tanks, including practically all the methods in vogue during the past six years, even down to one of Mr. Dibdin's new slate contact beds, which was being installed when I visited the works in April, 1904.* I was informed by Mr. Harrison that the later experiments had followed the same general lines as the earlier ones, only that they had been extended to cover other methods. It had been found that double contact beds, dosed with crude sewage, sludge up; that a closed septic tank and single contact beds effected a purification of 75 to 85% on the crude sewage; that the Ducat filter, housed in the dark, kept heated in cold weather, provided with tipping trough for automatic dosing, and having side walls of open drain pipe, did good work, but was prohibitive in cost, and also sludged up, due to fine material; that closed septic tanks gave no better results than open ones, and, finally, that the conclusions of the experiments show that a good effluent can be obtained with continuous or percolating sprinkler filters of coarse

*The "Report on Sewage Disposal," made in July, 1900, and signed by Messrs. Hewson and Harrison, already named, and by Mr. T. Walter Harding, M. Inst. M. E., Chairman of the Sewage Works Committee, and since made a member of the Royal Commission on Sewage Disposal, is one of the clearest and most interesting reviews of a series of sewage experiments which I have ever seen. It is to be hoped that a like report covering the later work will soon be issued.

material, supplied with either crude sewage or a well-treated effluent from chemical precipitation works, to be followed, in case crude sewage was applied, by sedimentation. It has been found that the suspended matter from the percolating filters receiving either crude, settled or septic sewage, is largely mineral, and is not putrescible, the organic matter being present as humus; and that deposits in such filters can be readily flushed out. At the smaller works already mentioned a large continuous filter, with a revolving sprinkler, is being filled with pebbles as large as a man's head.

Leeds has a veritable museum of experimental sewage works, some abandoned, some in use and others under construction. Many are on a small scale, but some of the most important beds have been made with units as large as those commonly found in practice. What Leeds itself does as an outcome of its experiments, which have now been in progress nearly seven years, will be a matter of no little interest and moment.

APPENDIX I.

Notes on a Sewage Settling and Screening Plant at Wiesbaden, Settling Tanks at Frankfort-on-Main and the Sewage Farms of Paris.

During a brief Continental trip in May, 1904, I had an opportunity to visit two of the Paris sewage farms, and also the sewage works at Frankfort-on-Main and Wiesbaden. The Wiesbaden works depend largely upon both fixed and mechanically operated screens for clearing the sewage of suspended matter, and are quite different from anything else I have ever seen. The Frankfort works are notable for having been changed from chemical precipitation to natural sedimentation, and then further changed by having the period of sedimentation cut in half, both by imperial order, or, at least, consent. The sewage farms of Paris are almost too well known to need any further description, and, considering their magnitude, my notes on them will be relatively brief.

SETTLING AND SCREENING AT WIESBADEN.

Wiesbaden has a population of about 100,000. It is a water closet town, with sanitary and storm sewers combined. All the sewage reaches the works by gravity. The final effluent passes through a ditch, or small stream, to the Rhine; and so, after the first screening described in the following lines, does one-third of the dry weather flow. The storm flow has no treatment.

On arriving at the works the sewage passes upward through a horizontal screen, then through an inclined screen, which can be lifted for cleaning, and then through one of six screens which, for purposes of cleaning, are mounted on a horizontal axle. The screened sewage then flows through a long detritus channel, from which the deposit is removed by scoops.

The sewage is next delivered in succession onto two sets of horizontal sieves, one at a higher elevation and of coarser mesh than the other. Both sets of screens are cleaned by revolving brushes,

driven by a 1-HP. electric motor. The brushes sweep the screenings, which appear to be mostly small bits of paper, into a trough, which is cleaned by hand.

After the sieve-screening, grease is skimmed from the sewage. This is barrelled and sold. The sewage next passes into a short channel, where, some years ago, lime was added, and on into settling tanks, provided with under and over baffle boards.

The effluent is dark and turbid, but contains no large particles of suspended matter. Before going to the Rhine it is utilized to drive a turbine which operates a dynamo used for power and to light the sewage works.

The sludge from the settling tanks is pumped 1.5 kilometers, or about a mile, with a lift of 28 meters, or about 92 ft., and left to drain and evaporate. Nothing further is done with it.

For my visit to these works I was indebted to Mr. H. P. N. Halbertsma, Engineer-director of the water, gas and electric light works of Wiesbaden. Mr. Frensch is engineer-in-chief of the department which controls the sewers.

THE FRANKFORT SETTLING TANKS.

The sewage works of Frankfort-on-Main were designed and carried out under the direction of the former municipal engineer, Mr. W. H. Lindley, M. Inst. C. E., in the year 1883.

The complete design consisted of twelve settling tanks, in two groups of six each, provided with the necessary engine house and its flood water pumps, sand catchpits and screens. The station was designed to deal with 40,000 cu. m. per day of dry weather and 80,000 cu. m. of storm water flow (about 10,000,000 and 20,000,000 U. S. gallons, respectively).

In 1883 four of these tanks were built, each 82.4 meters, or about 270 ft., long, with an average breadth of 5.7 meters, or about 18 ft., and depths varying from 2 to 3 meters, or 6½ to 10 ft. The normal velocity of the sewage passing through the galleries was 4 mm., or 0.16-in., per sec. As the government required a chemical treatment, lime and sulphate of alumina were used. These galleries were capable of dealing with the sewage of 140,000 inhabitants.

Owing to the increase of population (now over 300,000) the city authorities were obliged to enlarge the station. The government has now withdrawn its restrictions, and the number of tanks is being increased to seven, which, in turn, are divided in two cham-

bers, each chamber having its sludge suction pipe and two sumps, with bottoms sloping downward to the sump.

A new design of automatic, self-cleansing, revolving screens has been adopted for the sand catchpits. The city disposes of its sludge on land.

THE SEWAGE FARMS OF PARIS.

The four sewage farms of Paris have a combined area of 5,400 hectares, or 13,338 acres. The oldest of these, at Gennevilliers, is some 35 years old, and here is the "Model Garden for the Agricultural Utilization of Sewage." Acheres is next in point of age, and Pierrelaye and Carrieres and Triel have been in use but a short time. Through the kindness of Mr. Ernest Pontzen, Cor. M. Am. Soc. C. E., I was introduced to Mr. George Bechmann, Chief Engineer of the Paris water-works and sewers, who kindly arranged a visit to Gennevilliers and Pierrelaye, and several of the large sewage pumping stations besides. Mr. Pontzen accompanied me to Pierrelaye.

The sewers of Paris were originally built to convey storm water and slops only, and water closet connections were prohibited. Subsequently water closet connections were permitted, and now they are to be found in about half the houses of the city. It is expected that all privies and cesspools will be abolished within ten years.

The sewage of Paris now amounts to about 700,000 cu. m., or 185,000,000 U. S. gallons, a day, of which all but 100,000 cu. m., or 26,400,000 U. S. gallons, are pumped at Clichy. From Clichy a force main 28 kilos, or 17.36 miles, long leads to Carrieres and Triel, with connections to three other farms, but at Colombes much of the sewage is repumped. At Pierrelaye, also, repumping is necessary to serve a portion of that farm. The rise from Clichy to Colombes is 5 meters, or about 16 ft.; at Colombes the lift is 36 meters, or 118 ft., and at Pierrelaye, 25 meters, or about 83 ft.

At Clichy the sewage passes through a detritus tank, from which the deposit is removed by a dredge mounted on a movable car. The deposit is boated away. After a rough screening the sewage passes through fine screens, cleaned by rakes mounted on chain belts. The rakings are dropped into a chain conveyor and removed to a destructor. They amount to some 35,000 kilograms, or 77,000 lbs., a day. The pumps here are centrifugal, and all but one are driven by steam engines. The exception is an emergency pump, driven by a three-phase, 5,500-volt, electric motor.

At Colombes there are three detritus tanks, about 30 x 100 ft. in plan, from which the deposit is also dredged. The pumping equipment includes 18 400-HP. horizontal, compound, plunger pumping engines, with a daily capacity of 48,000 cu. m., or 12,600,000 U. S. gallons, a day each. The pumpage here ranges from 400,000 cu. m., or about 105,000,000 U. S., gallons, in winter, to 650,000 cu. m., or about 170,000,000 gallons, in summer.

There are no detritus tanks or screens at the pumping station (1,000-HP.) at Pierrelaye, but the proprietors of some of the privately owned land comprising this farm have constructed shallow basins at the outlet chambers, in order to lessen the felt-like deposit on the land.

The land now owned or leased by the city is not considered sufficient for the present volume of sewage. The areas of the four farms are as follows: Gennevilliers, 900 hectares; Acheres, 1,200; Pierrelaye, 1,800; Carrieres and Triel, 1,500; total, 5,400 hectares, or 13,338 acres. At the standard Paris rate of 40,000 cu. m. per hectare, or 4,300,000 U. S. gallons per acre, per year, this area could receive a total of 216,000,000 cu. m., or 57,000,000,000 U. S. gallons. This would be nearly 160,000,000 gallons a day, or less than 12,000 U. S. gallons per acre per day.

Gennevilliers Farm.—I saw only a small part of this farm, and that was the model garden. This was laid out in fruit and flowers and made a fine appearance. Effluent 6 to 15 ins. deep, in a gravel-bottomed channel 5 ft. wide, looked as clear as a mountain stream.

Some experiments on the so-called bacterial system of treating sewage have been conducted here. Two small, closed septic tanks and some double contact beds were put down about five years ago, and an open septic tank and some contact beds about three years ago.

The open septic tank is about 25 x 25 ft. in plan, and was entirely covered by a growth of green plants with tiny trefoil leaves lying flat on the sewage, with filaments perhaps ½-in. long extending into the sewage. The attendant said that the growth had been present from the start. There are three contact beds here, about 9 x 35 ft. in plan. One bed was composed of coal cinders, or clinker, one of gravel, and one of stone. The beds have been operated at the rate of 600,000 cu. m. per hectare per year, as compared with the 40,000 standard for the sewage farm.

Pierrelaye Farm.—I drove for several miles over this farm, which is composed of rolling land. The sewage is delivered in closed conduits to concrete outlet chambers, and from the latter it is distributed in simple ditches. The city owns and farms some of the land, but much of it is privately owned and operated. To the latter the city delivers the sewage at the outlet chambers. The crops raised include peas, artichokes, tomatoes and grass. The city farmer pastures several hundred head of market cattle, and also 300 to 400 horses. The latter are sent out from the city to recuperate, and bring the city 1½ francs, or 30 cts., per head per day. There being no suitable water supply on the land for so much stock, water is pumped from a well by means of a turbine driven by the sewage effluent.

This farm is some five years old. It surrounds the village or commune of Pierrelaye. There was opposition to the establishment of the farm, on the ground that it would cause typhoid fever in the village. No such results have followed, and the population of the village has increased from 1,500 to 2,000 since the farm was laid out. The village did suffer from flooded cellars, due to the fact that the land receiving sewage is above the village, and is underlaid by permeable soil of great depth. The farm is not underdrained, except by trenches, and the applied sewage passed through the permeable soil into the cellars of the houses. Drains were dug to protect the cellars. The commune has a fine looking mairie, or town hall, with lace curtains at its windows, built partly from an indemnity paid by the city of Paris.

The city is prohibited from applying sewage within a specified distance of the village, and is not allowed to apply more than an equivalent of 4 meters, or about 13 ft., in depth per year. Nor can it apply sewage to strawberries or salad crops; that is, to any crop the edible portion of which is touched by the sewage and is eaten without being cooked.

With the exception of considerable black sediment in the distributing ditches, everything I saw on or about the farm seemed to be in good condition.

APPENDIX II.

Definitions or Brief Descriptions of Typical Processes of Sewage Treatment.

The following definitions, or brief descriptions, of typical processes of sewage treatment are designed for any readers who may not be thoroughly familiar with the subject, particularly in its more recent phases. It is also hoped that they will aid in making clear the relations between the several processes. With the latter end in view, the definitions have been arranged in what may be termed a logical instead of an alphabetical order.

SCREENING.—This removes the coarser suspended matters by means of vertical or inclined bars, set with spaces between them, or else by means of a network of wire or metal rods. The screens may be cleaned by hand or by automatic rakes or brushes. Sometimes revolving screens, cleaned by fixed brushes, are used.

SEDIMENTATION.—Suspended matters are removed by affording an opportunity for them to be acted upon by gravity and carried to the bottom of a receptacle. If the time is so brief that only the heavy, mineral matters are deposited, the receptacle is called a catch pit, grit or detritus chamber. If the period is long enough to permit the deposit of lighter matters, the receptacle is called a settling or sedimentation tank or reservoir. Such tanks may be operated on the intermittent or the continuous plan, also known as the quiescent and the fill-and-draw systems. Intermittent tanks are filled, stand full, and then have the partially clarified liquid decanted, leaving the sludge for separate removal. Continuous tanks have the sewage flowing through them in a slow stream, the partially clarified liquid being drawn off at the top, over weirs or otherwise.

CHEMICAL PRECIPITATION.—Chemicals are used to assist or hasten sedimentation, thereby removing practically all the suspended matter. The sludge, or matter thrown down, is greater in quantity than results with sedimentation alone, besides which the chemical used and the water taken up by it is added to the sludge.

The sludge produced by sedimentation is frequently run onto land or onto filter beds, and left there for the water to drain and dry out. The same procedure may sometimes, although rarely, be adopted for the larger volume of sludge produced by chemical precipitation. As a rule, such sludge is made partially dry by means of filter-presses.

SEPTIC TANK.—Before the principles of bacterial action were known people marvelled at the number of years which a cesspool built with open walls and in an open soil could be left uncleaned, and yet never become filled with solid matter. A septic tank may be described as an elongated cesspool of far less relative capacity than the ordinary cesspool; or as an enlarged settling tank, designed to retain solid organic matter until it has been more or less liquefied and gasified. The sewage flows in at one end and out at the other, commonly through submerged inlets and outlets. The tanks may be open or closed, according to local conditions. In the majority of septic tanks thus far built for municipalities the sludge must be removed at intervals of a year or less. A detritus tank is generally placed just ahead of the inlet to a septic tank, in order to retain mineral solids, which, of course, are not subject to liquefaction.

BROAD IRRIGATION OR SEWAGE FARMING.—We have here a combination of mechanical, biological and chemical action. The soil acts as a strainer, and at the same time affords a home for innumerable bacteria, which seize upon the organic matter in the sewage, transform it into plant food and gases, at the same time changing its chemical composition. The process is essentially one of oxidation and nitrification. The crops, dairy products or live stock produced on a sewage farm help reduce the cost of sewage treatment, but there is always a danger that the best sanitary results will be made secondary to the farming operations.

INTERMITTENT FILTRATION.—This is broad irrigation intensified, with the sacrifice of all, or nearly all, crops. In Great Britain the filtration areas are generally temporary, while in the United States they are permanent, and therefore constructed with more care and expense. In Great Britain intermittent filtration areas are generally merely portions of the most sandy or gravelly land available, while in the United States the intermittent filter beds are more or less artificial beds of sand, although often making use of material in its natural position. The sewage is applied to the

beds at regular intervals, and flows onto and through them continuously until it is shut off. The beds then drain and rest. Meanwhile a new supply of air, for the support of bacterial life, is drawn into the beds. In the United States such beds are constructed much like water filters, only without a layer of gravel at the bottom, and almost always with tile underdrains and with earth bottoms. The frequency of closing varies greatly with the size of the sand grains and the strength of the sewage.

CONTACT BEDS.—For these, coarse material is used, often placed in water-tight enclosures. The beds are filled with sewage, stand full, are emptied, and then stand empty. This operation is repeated from two to four times each 24 hours, with occasional longer periods of rest. The applied sewage generally receives prior treatment to reduce the matter in suspension, and, in some cases, to partially liquefy the solid organic matter. As a rule, the filtrate from a coarse-grained bed is applied to a bed composed of material of finer grain. The coarse beds are called primary and the fine beds secondary. The terms single contact beds and double contact beds are also used. The size of material for contact beds is sometimes as small as 1/4 to 1-in. for the primary, and 3/4 to 2 ins. for secondary beds. It may go beyond these extremes, more particularly in the case of secondary beds.

PERCOLATING FILTERS.—The essential features of percolating filters are that the method of applying the sewage and the size of the material are such that the sewage is continually percolating through the beds in the presence of and exposed to air. The sewage may be applied by means of sprinklers revolving in a horizontal plane, or by means of nozzles set in fixed pipes, or by means of perforated, fixed, open distributors. The object in any case is to effect a rain-like, even distribution of sewage over the whole surface of the bed. The material composing the bed is in large pieces, rarely less than, say, 3 ins. in greatest dimension, and sometimes as large as a man's head. The bottoms of such beds are water-tight, and are provided with channels for collecting the final effluent. The outer walls are laid as open as possible, either pigeon-hole style or of the material composing the beds, laid dry. Percolating filters may be either continuous or intermittent in action: that is the distributing apparatus may be operated continuously or intermittently. Percolating filters are sometimes called continuous filters, in contrast with

contact beds, in which case the term intermittent continuous filters is applied when the sprinklers or other distributors have alternate periods of action and rest. The name intermittent continuous filter is not only clumsy and self-contradictory, but it conflicts with the term intermittent filter.

GENERAL CONSIDERATIONS.—Broad irrigation, intermittent filtration, contact beds and percolating filters depend upon aerobic organisms, and septic tanks upon anaerobic organisms, for their action.* It is claimed by some that anaerobic or putrefactive action also takes place in contact beds, particularly in first contact beds and notably when the effluent from septic tanks is being treated. Chemical precipitation is a temporary check to all bacterial action. Sedimentation tends to beget septic or anaerobic action, and the same is generally true of long outlet sewers.

With the exception of screening, sedimentation and chemical precipitation, it is evident from what has just preceded that all the processes of sewage treatment defined have as their object the attainment of the maximum amount of change in sewage through bacterial action. All such processes are properly termed bacterial, and it is a questionable proceeding to appropriate the term bacterial processes to the septic tank, contact and percolating filters. Such an appropriation is far more common in Great Britain than in America, and has come about there because nearly all the scientific study devoted to sewage treatment in Great Britain has been of septic tanks, contact beds and percolating filters. The chief justification for such a restriction of the term is that the processes named aim to intensify bacterial action to the utmost extent.

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*The aerobic bacteria carry on their life processes in the presence, and the anaerobic in the absence, of air. Those organisms which have the faculty of adapting themselves to the presence or absence of air are called facultative bacteria.

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HARVARD ENGINEERING SCHOOL